Coordination Between Players in Musical Performance

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Declaration.

I hereby declare that I designed and executed the programme of research reported in this thesis, and that I am solely responsible for the composition of the thesis itself.

Dedication.

This thesis is dedicated to the greening of the groves of academe.

There is in souls a sympathy in sounds
And as the mind is pitched, the ear is pleased
With melting airs, or martial, brisk, or grave;
Some chord in unison with what we hear
Is touched within us, and the heart replies.

Cowper.

Abstract

This research is concerned with the timing of actions in the production of music. Musical skill presents a critical challenge for theories of information aquisition and action planning, as any comprehensive theory must be able to explain complex as well as simple behaviour. Nor can a reductionist explanation be validly generalised to more complex behaviour, as there are qualitative changes in the development of skill.

The first section of chapter one introduces this problem and considers the phenomenon of music, concluding that it is a celebration of intersubjectivity and principles of organisation. The second section reviews the various models that have been proposed to account for the serial ordering and timing problems involved in playing music. The third section looks at the role of the conductor in coordinating musicians and communicating details of timing structure. The final section presents the experimental approach and methodology of chapters two to four.

The second chapter examines the interaction of multiple sources of timing information, concluding that the normal role of the conductor is to provide general, rather than precise, timing information, and that musicians normally look to each other for precise synchrony.

The third chapter examines the nature of the beat to see how the conductor communicates a series of points in time with a baton

in continuous motion. The feature of the baton trajectory that most closely corresponds to the beat proves to be the Y-axis minima. It is also established that the underlying rhythm does not correspond precisely to the beat, but stands in a structured relationship to it.

The fourth chapter looks at the principles of communication to see how the conductor tells the musicians how and when to play, and concludes that this is done by holding constant all parameters of movement except those that are used in direct proportion to communicate the essential details. Exactly the same principle is adopted by the musicians in actualising these requirements.

Chapter five introduces the second series of experiments, reviews the problems of modelling the musical situation, outlines the principal questions dealt with in chapters six to eight, and describes the methodology in common to these chapters.

Chapter six examines the detection of visual-auditory asynchrony, and proves that the subjects would first select an offset and then replicate it, indicating that this is in fact a two-stage process.

Chapter seven finds that if subjects are required to synchronise with an isochronic target series they will spontaneously group their responses. It is suggested that this reflects the operation of the planning and motor system.

Chapter eight reports on four experiments. The first compared information modalities, concluding that subjects can track an auditory series more accurately than a visual one, and, where both are present and offset, will track the auditory series in preference. It is suggested that this underlies the finding of chapter two. It also emerges that entrainment and synchronisation are separate processes, which supports the finding of chapter six. The second experiment analysed the variance of grouped taps and discovered that, while taps were grouped, the variance was homogeneous. The third experiment found that when subjects had to attempt to minimise asynchrony by actively tapping a switch, this entailed additional error variance as compared to their passive judgement of asynchrony in chapter six. The fourth experiment goes further into the relationship between tempo and accuracy that is observed in several earlier chapters.

Chapter nine discusses the problem posed by the study of music for a reductionist and dualistic model of science. The historical development and context of this model is reviewed. It becomes apparent that this model has only a limited domain of applicability, and that we are consequently engaged in a paradigm revolution. The emergent paradigm, based on an ecological philosophy, is outlined.

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Contents

Chapter one

Introduction

Abstract

This introductory chapter consists of four sections. The first examines the phenomenon of music. The second reviews the various models that have been proposed to account for the serial ordering and timing factors involved in playing music. The third section considers the role of the conductor in coordinating groups of musicians and communicating details of timing structure. The fourth section presents those elements of the experimental approach and methodology that are common to the first three experimental chapters, chapters two to four.

Introduction

This thesis is concerned with the aquisition of timing information, and its incorporation into what Bernstein (1967) termed biodynamic structures. Now, any comprehensive model of this behaviour must be able to explain complex as well as simple instances. In general, to assume that complex behaviour can in principle be understod by studying only simpler instances is to make critical assumptions about the nature of the phenomenon. These assumptions may preclude genuine understanding. For example, to assume that complex perceptions are necessarily composed of assemblages of simple operations is to overlook the relational effect and the way in which structure is perceived as a meaningful gestalt.

An understanding of the complex behaviour, on the other hand, provides a context for the comprehension of limited instances and simpler patterns of behaviour. These problems are further reviewed in chapter nine.

The decision was therefore made at the outset to study the most complex and subtle timing problems, those involved in musical skill.

The remainder of this introductory chapter is in four parts. The first part contains a brief note on the nature of music itself. The second part reviews some of the attempts made to understand the timing mechanisms involved in the understanding and excecution of music. For music involving several players, there must be a further level of coordination, which has required the evolution of the role of the conductor. The third part of this chapter accordingly describes the role of the conductor, which is investigated in chapters two to four. The fourth and final part describes those elements of the methodology which are common to the experimental approaches taken to problems that are explored in these first three experimental chapters.

Part one. The nature of the phenomenon.

"If ya have to ask - ya aint got it" - Duke Ellington.

What is music? Williams (1967) argues that it is one of the most uniquely human of all our activities, as art in general, and music in particular arise out of a sense of self-awareness. This may be true, but it is not an explanation.

Levi-Strauss wrote that-

> "Music is the supreme mystery amongst human knowledge. All other sciences stumble into it. It holds the key to their progress."

The potential literal truth of that last sentence is suggested by Jones, a research fellow at London University, who wrote an article published in the Guardian in 1981 in which he pointed out that the way to understanding thought processes might be through the study of music. The argument runs as follows. Linear logic is a limited formal system, which has been adopted as a model for the decision making sequences in computer design. However, it is unlikely that it represents the way in which the mind itself operates. A more fruitful route to the understanding of the mind, Jones suggests, has been through the study of language. Fournie (1887) wrote on the subject.

> "Speech is the only window through which the physiologist can view the cerebral life."

However, there is another area of specifically human activity where, as in language, temporally patterned sequences are developed in a sophisticated structured form. This, of course, is music.

The relationship between music and speech has been noted by others. Revesz (1954) reviewed various theories of the origin of music and concluded that it lay in the need for mutual understanding and contact. Music, he stated, has its origin in speech and language. Lerdahl and Jackendorff (1977) have shown that the structure of prosodic stresses is similar in speech and music. Similarly, Janacek wrote that-

> "No-one can compose music until they have first studied living speech- this should be clearly understood, once and for all."

Others have extended this notion to suggest that musicians should become more aware of the parallels with other biological processes. Ozawa comments that it is necessary to conduct the Pastorale as if breathing. Rubinstein conveys a similar notion of tension and relaxation.

> "It's not how I play the notes- it's how I play the spaces in between."

Zappa argues that music should not be written as equal and precisely fractioned intervals, but should actually be notated in the uneven but rhythmic patterns of speech, although he admits this looks extremely complex on paper.

Minsky, one of the founders of the science of artificial intelligence, collaborated with Boulez in a series of seminars on the composer and the computer in 1980, and developed a theory of mind based on the analysis of musical composition. The mind may operate at many levels, and one thought process may be monitored by another, with the second level providing sequence planning to allow for smooth transitions between the elements of the first level. The process is therefore analogous to movement control, as will be seen in the next section of this chapter.

The second level may itself be monitored by deeper levels. Thus the best analogy is that parallel processes operate in counterpoint. This is directly comparable with musical composition where many parts proceed, apparently independently, yet intrinsically interwoven.

In the aquisition of a skill, such as driving a car or playing the piano, one of the key problems is the necessity to progress from the need to monitor individual feet or hands to a position where a higher level decision can be smoothly actualised with the necessary motor components acting in a coordinated fashion. This exactly parallels the switch from sequential or linear to multi-level counterpoint thinking. At higher levels yet, an organist may have three or four lines of action to merge, a conductor may have scores of sequences to integrate.

The contrapuntal monitoring model helps to explain how people can employ extremely complex rhythms. Indian ragas can have from three to one hundred and eight beats per cycle, and have to be accomodated within time windows defined by other rhythms. While the attention must be partly concentrated on maintaining a regular sequence of beats, some parallel process must monitor the rest of the musical structure so that the beat series can be smoothly accelerated or decelerated if necessary to allow the series to resolve exactly at the place required.

While music, according to this argument, may gain some of its power from its modelling of human biology, be it breathing or thought processes, there are other indications that music reflects interpersonal communication at a fundamental level. In this respect it is similar to other tasks where motor output must be coordinated. Consider the following examples.

The first is from twins, who are piano virtuosos, Suher and Guher Pekinel.

> "We never look at each other when we play...we feel that the slightest contact disturbs the concentration. We react to each other only with the emotion. The reaction should go immediately through the hands and not the eyes. We have only contact with the back."

The second is also from twins, Charles and David Ivatt, top Scottish oarsmen. During the senior pairs at Newark regatta in 1981 they increased the rate three times in the last seven hundred and fifty metres, which is not a common tactic. Normally the stroke in a coxless pair warns his partner that he is increasing the pace. The Ivatts did it without speaking or planning.

> "We just seem to know when to take it up or down...David dos'nt have to say, somehow I know instinctively."

The final example concerns the repentistas. They are street musicians in Brazil, who often work in pairs. Each will take turns at improvising rhythms and comments for an indeterminate time, up to thirty minutes in a turn. Then the other will take up the delivery. The good repentistas pride themselves on seamless hand-overs, but give each other no warning other than a slight extra stress on the last beats. The second repentista is expected to pick up the rhyme as well as the rhythm.

All these examples indicate a true intersubjectivity, where each participant can take the part of the other. If it were not for this shared understanding, it is difficult to see how these moments of coordination could occur. Music can be understood as a celebration of this process of sharing, as it is this intersubjectivity raised to an art form.

McElheren (1966) points out that one of the roles of the conductor is to get inside the intentions of the composer and to recreate, from the skeleton of the score, the living idea that was the original of the music. He suggests that this is achieved by thinking at the level of the music, not of the mechanical actions. This is a less immediate intersubjectivity, but must also be based on some shared element of human experience.

The role of music in expressing principles of organisation-intellectual, emotional, or motoric- can also be seen in the process of generation of concepts and musical composition. Several composers have commented that they felt the process of creativity as passing through them, rather than emanating from them.

Stravinsky said-

> "I had only my ear to help me- I heard, and I wrote what I heard. I am the vessel, through which the Rite of Spring passed."

Mozart (in Holmes, 1878) wrote that-

> "Whence and how (my ideas) come, I know not; nor can I force them...nor do I hear in my imagination the parts successively, but I hear them, as it were, all at once (gleich alles zusammen)...the committing to paper is done quickly enough, for everything is, as I have said before, already finished...why my productions take from my hand that particular form and style that makes them Mozartish, and different from the works of other composers, is probably owing to the same cause which renders my nose so large or so aquiline, or, in short, makes it Mozart's, and different from those of other people. For I really do not study or aim at any originality."

Tchaikovsky (in Newmarch, 1906) wrote as follows.

> "The germ of a future composition comes suddenly and unexpectedly."

Spender (in Ghiselin, 1952) wrote-

> "At the moment when art attains its highest attainment it reaches beyond its medium of words or paints or music, and the artist finds himself realizing that these instruments are inadaquate to the spirit of what he is trying to say."

Similarly, Einstein reported that he first intuited his principle of relativity in terms of bodily sensations. It was the transcription into mathematical form that he found difficult.

Revesz (1954) reviews what he terms the two concepts of creativity, the "unconscious" or "metaphysical" and the "psychological". He provides the following quotes from Goethe, Nietzsche, Brahms, and Mahler to support the first position.

> "the artist is like a vessel..found worthy to receive a divine inflow." - Goethe

> "Everything takes place involuntarily to a high degree, but as in a tempestuous feeling of freedom, of unconditionality, of power, of divinity." - Nietzsche

> "That which in general is called invention, i.e., the thought, the idea, is simply a higher inspiration for which the artist is not responsible, for which he can claim no credit." - Brahms

> "The creation and the genesis of a work is mystical from beginning to end since one, himself unconscious, must create something as though from outside inspiration. And afterwards he scarcely understands how it happened." - Mahler

On the other hand, Revesz argues, is it necessary to assume forces that lie outside the productive personality, and cannot be comprehended empirically, or that musical inspiration cannot be explained in a natural way, i.e., that it could not be deduced from the creative process and its antecedents, concommitants, and consequences in their entirety? Certainly, there is evidence that Haydn, Beethoven, Schubert, and Schumann worked extremely hard in the process of composition, pruning, polishing, altering, and refining. Beethoven's early drafts were, on occasion, quite clumsy. Even Mozart was immersed in music for years before he wrote the Don Giovanni overture in one night. These quotes from Wagner, Stravinsky, and Nietzsche make the point.

> "Do not estimate the power of reflection too lightly. The art work of the crowning period of civilisation cannot be produced otherwise than consciously." - Wagner

> "For me as composer, composing is a daily routine which I feel called on to carry out. As every organ deteriorates if it is not kept in running order, so the abilities of the composer decline and petrify if he does not make a constant and zealous effort to keep himself in practice. The layman thinks that in order to create, one must await an inspiration. Quite to the contrary. I consider it to be a moving force that belongs to every human activity and is

> by no means a monopoly of the artist. But this power only unfolds when it is set in motion by an effort and this effort is work. Just as appetite comes with eating, so does work evoke inspiration, in the event the latter is not present from the beginning. But it is not a question of inspiration alone, but of the result: the artwork." - Stravinsky

> "It is to the interest of the artist that others should believe in sudden inspirations; as if the idea of the artwork, the poem, the underlying thought of a philosophy shone down from heaven like a divine ray. All great men were great workers, indefatigable not only in invention but also in rejection, sorting out, revising, and arranging." - Nietzsche

Revesz concludes that there are limits to our investigative abilities. We cannot grasp the forces that govern original creative work, which often surprise even the artist. The creative idea is a natural phenomenon, rooted inside us, which is perhaps why we cannot see these deepest roots.

Sinnot (1959) agrees that these flashes of inspiration rarely come unless an individual is immersed in a subject.

> "Just as the organism pulls together random, formless stuff into the patterned system of structure and function in the body, so the unconscious mind seems to select and arrange and correlate these ideas and images into a pattern. The resemblance between the two processes is close. The concept is worth considering that the organising power of life, manifest in mind as well as in body- for the two are hardly separable- is the truly creative element. Creativity thus becomes an attribute of life."

Sinnott concludes that the biological basis of creativity is that-

> "life is the creative force by virtue of its organising, pattern-forming...quality."

Gerard (1946) gives more detail on this point, and makes the explicit analogy with music.

> "By such various mechanisms, then, great masses of nerve cells- the brain as a great unity- act together; and not merely do two or a billion units sum their separate contributions, but each is part of a dynamic fluctuating activity pattern of the whole. This is the orchestra which plays thoughts of truth and beauty, which creates imagination...What a beautiful basis for making new gestalts or recombinations of sensory material!"

These expressions suggest that these composers felt that the generating idea of their expressed concepts lay in, and their output reflected, some fundamental organising principle, be it of physics or one of the manifestations of biology, which they recognised in other beings and existence other than themselves. This would account for the feeling that they were not the originators of these ideas, but rather a part of the processes that were reflected in these ideas.

The uniquely human element of music postulated by Williams may, then, lie in the human capacity for self-awareness and our ability to generate abstract representations of operating principles. One of these abstract representations could be music.

Part Two. Studies of Timing.

In order to understand the specific problem of timing in music, it is necessary to start with the general question of how actions are timed relative to an environment. This problem arises in different situations. Firstly, consider how people time the individual components of an action with respect to each other, in order to achieve an overall coordination. When reaching out for a cup, for example, the arm extension, finger spreading and contraction in the grasp must all be appropriately timed as phases of that particular action. If any component was mistimed, which could happen if, for example, the distance was misjudged, the action could be unsuccessful. That is, the cup could be knocked over. At least the cup is not normally moving relative to oneself. The situation becomes more complicated when one tries to intercept something which is itself in motion. A good example here would be running to catch a falling ball. Here one must not only organize the correct internal sequencing of one's actions in getting a hand to a particular location in space, one must have that hand there and ready by a particular time which cannot be defined with reference to the body- system alone. The time is defined also by the movement characteristics of an external object and the coordinates in space and time at which the decision has been made to attempt to intercept it. In this situation the internal sequencing of the appropriate actions must be controlled and geared towards this temporal constraint, to which at least the final phase of the intercepting action must be closely geared. The preceding sequence of actions that are the necessary precursors of the intercepting action (for example, the running as opposed to the catching) is obviously also geared towards the same time but it is not necessary that they be as precisely regulated.

Two conclusions emerge from this. The first conclusion is that because it is possible to intercept moving objects, it must be possible to anticipate a trajectory, and arrive at a contact time or at a time-to-collision.

How might this be done? Any valid theory must be able to explain the possible permutations of movement of the observer or of the observed: when the object is moving and the observer is stationary, where the person is moving and the object is stationary, and where both are moving relative to a broader context. Lee and colleagues, for example, have looked at people leaping to punch a falling ball (Lee et al, 1983), gannets plunge-diving towards the sea (Lee and Reddish, 1981), and at how drivers control the rate of braking of automobiles (Lee, 1976). What Lee et al (1983) describe is a means whereby time-to-contact might be registered directly. If approach is at a constant velocity, the image of the object in the optic array will be dilating, and the inverse of the rate of dilation (which is defined as _tau_) is equal to the time-to-contact. One advantage of the adoption of a _tau_-based strategy is that it would avoid the dual sources of possible error involved in a computation of time-to-arrival from distance and speed.

In fact, Schiff and Detwiler (1979) have demonstrated that subjects require neither distance nor velocity information to perceive time-to-contact under conditions of constant approach velocity. Under conditions of acceleration, as obtained in the falling ball experiment, the <u>tau</u> strategy might still hold. This is because <u>tau</u> provides an increasingly good estimate of time-to-contact as the moment of contact approaches, especially from about -300ms onwards. This <u>tau</u> parameter, being directly deriveable from the optic flow, could be a basic or primary variable upon which judgements of time and distance are subsequently based or calibrated. Drivers could control deceleration by means of the time derivative of this optic parameter <u>tau</u>, the value of which specifies whether or not the current braking force is adaquate to stop before reaching the obstacle.

The second conclusion that emerges is as follows. When actions, or action components, are sequentially organised and timed with respect to external events, or to each other, there is a certain selected rate implicated in the way the reach and grasp are excecuted. Therefore the terminal coordinates towards which a movement is directed must include time, the terminal coordinate in the fourth dimension, in addition to the coordinates of the first three dimensions, which may be defined in egocentric spatial coordinates. The terminal temporal coordinate therefore determines the nature and meaning of the action as much as the terminal spatial coordinates. This is the essential common feature in the different permutations of observer-observed movement described earlier, although the tasks may differ in complexity or in other ways, such as the quality of performance, when factors such as familiarity and skill level must be taken into account.

Probably the most complex of all timing problems are those facing musicians. First consider a relatively simple situation, a musician playing a solo. If there is a sequence of notes to play, and a set tempo, then this will generate a series of points in time towards which the musician must time his actions. Thus, at any given moment, there is a constraint, external to the action itself, but towards which the action must be geared. This is true even when the constraint only exists inside the musician's head. This must be so because musicians know when they miss a beat and their timing goes out. Therefore there must be a representation of the beat which exists independently of the action itself. Lee (personal communication) can play his clarinet solo and syncopate. As there is no rhythm section present, the beat from which he is off-setting does not actually exist except as an image of a series of times in his mind around which he can gear his actions. I myself find that I can be aware of playing off the rhythm, or on the beat, or even arhythmically. This can only be defined with reference to a sense of ongoing beats which arises from my playing and yet has some mode of semi-independent existence.

To play rhythmically is, therefore, structurally analogous to the catching task described above. The principal difference is that in the musical situation actions are almost always geared towards a continuous sequence of times-to-arrival. Furthermore, these will not necessarily be equidistant in time. So it is necessary to think in terms of a more abstract, although otherwise similar, idea of "collision time".

The problem of how people establish the correct time and periodicity is, then, a parallel line of research to studying how people establish a time-to-collision from tracking the trajectory of, for example, a falling ball though of course the situations differ in terms of the type of information available and also in terms of the types of solutions that people adopt.

Now, what happens when there are two or more people playing together? How do they get their respective sequences of times of the correct and matched duration and in the same place? The task is rendered considerably more complex by the fact that there is a wide variation in the response characteristics of different instruments. With a drum, for example, the note sounds almost as the drum is struck (we have measured this to be within approximately 0.5ms). With a large organ, there may be a second or more between when the key is pressed and the note sounds. To keep this diversity harmonious requires a clearly established time series with respect to which the players can gear the various different movements, each with their different temporal characteristics.

This need underlies the fact that with the evolution of the orchestra there was a concommitant evolution of the importance of the role of the conductor. This role is discussed further in the next section of this chapter. One aspect of this role, though this is not always the most essential part, is to establish the common tempo and timing structure. The job is to perform this task explicitly, so that all players can see, establish, and maintain contact with the common time series. This means that conductors are good candidates for study in an analysis of temporal coordination and communication, because their role is to establish a time-to-contact or a continuous sequence of times-to-contact and to communicate it, which must (due to the size of the contemporary orchestra) normally be done visually.

This situation therefore allows a comparison with the falling ball. That is, is there a lawful predictability about the gestures a conductor makes and amplifies with his baton that would allow musicians to derive a time-to-contact with confidence, so that they could gear an action appropriate to an instrument so that the note emerged at the time specified? Is the predictability afforded by the conductor really comparable with the lawfulness of effect which derives, in the ball-catching situation, from the force of gravity? This question is dealt with in chapter three.

The remainder of this section reviews some of the attempts made to define the principles of timing and coordination. The essential model that emerges from the greater part of the literature involves three principal stages. The first concerns intention, which is discussed in the next section of this chapter. The structure of intention in the musical domain has been studied by Steedman (reference note 1.1), who has started to devise a generative grammar for blues jazz chord sequences. Longuet-Higgins and Lee (1982) have started to construct a model of the role of expectation and inference in structuring perceived rhythm. Of the other two stages, in accord with a distinction proposed by Shaffer (1981), one will be referred to as the control system, which is where serial ordering is effected, while the other will be referred to as the performance grammar, which consists of a set of rules for coordinating the movement sequences and actualising the movements required.

The purpose of this review will be to compare descriptions of the different stages, to discover which level is responsible for the timing of actions, to describe the mode of communication between the levels, to consider how this model of action integrates with perceptual processes, and to define the aquisition of skills.

Lashley (1951) demonstrated the need for an organisational level in action planning. He demolished the peripheralist associative chain theory of temporal integration associated with Watson (1920) and Washburn (1916). The key postulate in this theory was of the existence of chains of reflexes, in which the performance of each element in the series excites the next. Washburn distinguished "successive movement systems", defining these as

> "a combination of movements so linked together that the stimulus furnished by the actual performance of certain movements is required to bring about other movements."

She described speech, for example, as a succession of vocal acts in which the kinesthetic impulses resulting from each movement serve as a unique stimulus for the next in the series. Lashley demonstrated that this theory could not account for the syntax of language or the structure of movement.

He then considered the model proposed by the struturalist school, a centralist associative theory. Titchener (1909) objected to peripheralist theories, but still assumed that verbal thought is a chain of central processes in which each element serves to arouse the next by direct association. He maintained that the meaning of a word or "auditory image" consisted of the chain of association which it aroused, and that no meaning existed until such a sequence had occurred. He offered no explanation of how a succession of ideas might arise. Lashley concluded that this merely displaced the problem, and did not solve it.

Finally, he reviewed the concept of Bewusstseinslage, the idea of imageless thought. Pick (1913) developed this concept and concluded that pre-action thought contains no temporal information. Lashley further developed this notion, with the addition of the necessary planning stage without which the basic model was inadaquate. This, he suggested, was an independent stage, as syntax was not inherent in words employed, nor in the idea to be expressed, but a generalised pattern imposed on the specific acts as they occurred. He thus arrived at a three stage model. Stage one was the determining tendency. Stage two was the syntax of the act. Stage three was the activation of the expressive elements.

This was a very influential paper. The ideas, however, have been developed and refined.

Noteboom (1974) has provided evidence that utterances which are well formed with regard to serial order are still not understandable without additional constraints on the duration of individual phonemes, which entails some other level of organisation. Shaffer (1982) points out that, in the real world, motor events often occur in smooth succession, in a coordinated rather than phasic manner. This underlying continuity means that there must be pre-preparation of movements. This kind of planning is, in fact, a prerequisite for rhythm.

Estes (1972), Martin (1972) and Jones (1974, 1976a) also agree with Lashley that there must exist some hierarchic representations that are used to serially order behaviour. This does not solve, however, the problem of the timing of behaviour. The question addressed by Wing (1977), and Vorberg and Hambuch (1978) is whether both serial ordering and timing are achieved by the same mechanism, or whether timing is achieved at the level of the expressive units.

Shaffer (1981) describes two basic models of timing in performance, which apply in slightly different situations. One was developed by Michon (1967) to describe synchronisation with an external series of events. This model states that a response interval is set in advance by adding a correction factor to the remembered length of the last response interval. There are allowances in the model for responsiveness to feedback and damping in the system, which allows the effect of feedback to be distributed over a sequence of taps. This model is discussed in more detail in chapters six and eight. The other was developed by Reece (1976), and Wing and Kristofferson (1973a, 1973b), from an idea originally proposed by McGill (1962) and expanded by Ten Hoopen and Reuver (1967), and Fraisse and Voillaume (1971). McGill described a model for periodic responding which allows random fluctuations in the intervals between successive responses while preserving periodicity. The clock generates regular pulses, and each pulse produces a response after a random delay. According to this model, the correlation between one interval and the next should be -0.5. That is, a short response delay will prolong a subsequent interval by curtailing the previous one, giving rise to a negative correlation between successive inter-response intervals. McGill's first model did not allow a delay to run into the next pulse period, but a subsequent version incorporated that possibility. Wing arrived at a two stage model of timing of discrete responses, with the later versions of the model allowing for error variance at both stages. Stage one was a timekeeper, which output timing intervals, stage two was a response system, with an associated variable delay. This is closely related to the model proposed by Kozhevnikov and Chistovich (1965) for speech timing.

Wing (1977) then proceeded to test various possible models of interaction or dependence between these two levels, analysing the data in terms of the interresponse interval autocovariance function. His results supported the existence of both stages. Vorberg and Hambuch (1978) also tested this model for timing of interresponse intervals by requiring subjects to group responses. They found that the serial covariance function differed systematically from that predicted by the model, i.e., that the model could not account for higher order rhythmic groupings. To account for this, Vorberg and Hambuch then tested extensions of the basic Wing model and concluded that timekeepers appeared to be organised sequentially, in apparent contradiction to their earlier finding of higher order or hierarchical structuring.

To reconcile these findings, Vorberg and Hambuch suggest that serial ordering and timing of behaviour must be performed by separate mechanisms. Serial order thus appears to be a hierarchical tier of organisation, timing appears to be sequential. Thus Vorberg and Hambuch argue that a motor program specifies the identity of the individual movements and their succession, as well as the timing information. In the actualisation of the program it is translated into sequentially timed events. This model is compatible with that of Michon (1974), who found evidence for hierarchical organisation underlying serial ordering in speech and musical rhythms.

Povel (1977, 1981) proposed a different model, with a beat-based structure. This was an attempt to explain the findings of Fraisse (1946, 1956). In the earlier work, Fraisse reported that subjects tended to use a 2:1 ratio in imitating simple temporal patterns that actually varied between 2.18:1 and 3.25:1. Patterns of value less that 2:1 were rounded up, values greater than 2:1 were rounded down.

In the later work, Fraisse analysed a sample of Western music, and found that an average of 86% of the tone durations related in the proportion 2:1. Thus it appeared that there might be limitations on sequence perception or replication.

Povel contrasted three models. The first is the association model, where sequences of events are coded as a chain of durations. This model, as has been noted, cannot account for the grouping phenomenon reported by Vorberg and Hambuch, thus it is of limited applicability.

The second model is the completely hierarchical description proposed by Martin (1972), in which the shortest relative duration in the sequence is adopted as the basic unit. This model is limited by its inability to deal satisfactorily with triplets. It has also been applied by Michon (1974) to Satie's 'Vexations', to unconvincing effect.

The third model is Povel's beat-based model. Povel suggests that subjects map sequences onto an interval structure. Step one in this process is segmentation into equal intervals bordered by events. This is the beat interval. It is not clear how this interval is selected, but the selection may be influenced by accent level, tempo, and the subject's experience. Step two in the process is that intervals smaller than the beat interval are expressed as a subdivision, but the number of possible within-beat structures is limited. In fact, only equal intervals or a 2:1 ratio are acceptable. This is how Povel accounts for Fraisse's findings. This, then. is a partially heirarchical model, and is structurally similar to that proposed by Vorberg and Hambuch. The number of levels in Povel's heirarchy, however, is not fixed but depends on the selected beat intervals. Thus with more, and more complex, subdivisions the number of levels in the organisational hierarchy increases.

The critical limiting factor in this model is the insistence that subdivisions must be equal intervals. This is what results in the need to postulate increasing numbers of levels in the hierarchy, and also means that the model cannot explain the ability of musicians to reproduce non-equal intervals. Povel allows that non-equal coding could occur, although only with difficulty, but this then undermines the universality of his model.

Shaffer (1984) adopts some elements of Povel's model, agreeing that metre is mapped onto time scales generated by an accurate timekeeper. Shaffer, however, specifies that the player may chose the bar, or the beat, or a fraction of the beat as the appropriate metrical level.

The timekeeper is controlled by the motor program. The output-notes, in the case of the musician- are arranged by the motor procedure in relation to the pre-set time scales.

This now gives two levels of timekeeper. One paces the metre, and the other is implicit in the movement trajectories computed by the motor system in relation to the metre.

This more sophisticated model allows a proper consideration of rubato and expression in music. Expression is not an abberation, but what gives music vitality. It is therefore important, yet it is an embarrassment to simplistic models of timing.

Generation of real (i.e., with expression) from specified (i.e., in the score) temporal targets is clearly a reasonably lawful process, as evidenced by the accuracy with which Shaffer's subject's could replicate performances complete with expression. From this, it also follows that expressiveness occurs at the time-scaling process stage.

This process has been studied by Sloboda (1982,1983). The methodological problem is, of course, in separating intended from non-intended variations. Sloboda managed to do this rather elegantly, by varying the notated dynamics and comparing within and between trials. He concluded that stress may be indicated in a number of ways, structurally, by varying the volume, by use of legato, and by varying the inter-onset-interval. Certainly, expressive responses are not simply triggered by the notational symbols. This is thus a sophisticated process, possibly involving integrated contributions from the various levels of the motor programming hierarchy.

The model of motor programming that emerges is described by Shaffer (1981, 1982). It has two main components. The first component is a control system, which constructs a hierarchy of abstract representations of intended actions, and relays it in the form of a schedule. The second component is a performance grammar which generates the sequencing, and hence syntax, of movements, plus the specification of how they should be actualised.

This model allows there to be, within the set of rules that constitute the performance grammar, considerable jurisdiction in meeting the schedule provided by the control level. It allows the motor system to act as a timekeeper, counting down to the scheduled temporal targets specified by the control and actualising this time series in the movement. The set temporal goals are thus determining parameters of the movement. Cooke (1980), Sudnow (1978), and Kelso et al (1979) have all provided evidence that the motor system does in fact do this.

For each phase of movement, the reference point for the target could simply be the previous target. This development partly subsumes Michon's (1967) synchronisation model.

It is also possible that the limbs (for example) might already be in motion at the timing reference point. Experimental evidence for this is presented in chapter four. This would require that, as Kelso et al (1981) argue, that the motor control system is sensitive to its own dynamics.

This model also allows ready comprehension of compound movements, as phases of a movement could be grouped (giving rise to Vorberg and Hambuch's result), by the control system, while the motor system actualised the internal timing of the group.

Each of these two levels has, then, a qualitatively different kind of 'clock'.

Viviani and Terzuolo (1979), and Viviani (reference note 1.2), in a study of typing skills, found that the motor sequence for each word has an invariant and specific structure. That is, the ratio of successive time intervals between pairs of keystrokes proved to be independent of the speed with which the movement as a whole was executed.

Bernstein (1967) suggests that this phenomenon is in fact a general principal ("motor equivalence") in the space-time domain. Raibert (1977) has provided evidence for the existence of a higher level program by noting the similarities between samples of writing provided by the same person using the right hand, right arm, left hand, mouth, and right foot. Viviani and Terzuolo's results confirm that this homotetic behaviour is characteristic of learned motor skills, and suggest that the reason for this is that the representation at the command level is in terms of ratios between the timing of successive motor commands. Brown and Slater-Hammel (1949), Stetson (1905), Woodworth and Schlosberg (1954) and Hartson (1939) have all noted that as subjects are required to make longer movements they increase the speed of the movement, thus keeping the movement time approximately constant. Schlapp (1973) notes that when a word is hand written to different scales, the timing pattern is preserved, indicating that the size is determined by controlling the intensity of the muscle activations. Van der Gon (1965) found that the shape of the word written is determined by the timing of the muscle contractions, not by the magnitude of the forces used. The fact that a person's handwriting may be recognised almost irrespective of the scale or medium is, in fact, further evidence for the separation of the intention and the motor programme. Jones (1981) argues that this requires an inclusion of the concept of tacit knowledge (Polanyi and Prosch, 1975), as attention is directed from the graphemic details of the text to the meaning of the word, just as it is from the score to the music or from the action to the intention.

Viviani's study confirms that the figural and dynamic aspects of movements are reciprocally related, which indicates that spatial and temporal goal-setting is an integral process, as evidenced by the existence of "units of action".

It therefore appears that the command level clock must be programmable, and can be set to represent timing features, in an abstract homorphic form, of the output sequence. If so, it must be possible to set this clock in a periodic or an aperiodic mode. Its output is stochastic, in that the output code is in relative or ratio, rather than absolute form.

This output code consists of a series of targets. Clearly, these could not be isolated triggers of movements, as this would not allow continuity and coordination of actions. The output must therefore provide a continuous temporal reference for the motor system.

Shaffer (1984) discusses intermanual coordination of pianists, who can play with their hands going in and out of phase with each other. A guitarist called Stanley Jordan introduced a new guitar technique this year, in which he (he is the only known practitioner) plays three or even four guitar parts simultaneously.

The fact the separate hands can play interlocking parts, and play in and out of time with each other intentionally, is evidence either that this temporal reference output could be generated for individual units, or, more parsimoniously, that the set of instructions for action in relation to the reference could be generated for individual units. This means either that the control system can generate series of commands in parallel, or else that some kind of first-in first-out (FIFO) sequential access buffer exists in which the information, tagged for identification or otherwise insulated, could be stored. The separation would permit the hands to receive their information simultaneously.

The motor system could, if a FIFO buffer existed, then preview the schedule of events and arrange different modes of actualising them. That is, if the motor system references the schedule to get a sequence of times-to-arrival, which it then employs as the terminus of a countdown, it could do this separately for individual motor units. This would, then, explain how hands can play in and out of time.

The musical expressiveness mentioned earlier could in part be achieved, in fact, by a similar process of moves in and out of time with the schedule. It is thus possible that rubato may involve both a control level function and the motor system, with some dialogue required at changes of tempo. Greene (1972) made a similar proposal, arguing that the semi-autonomous motor effectors would operate within their limits of autonomy, re-involving the control level when the nature of the task changed excessively.

Peters (1981) points out that coordinated bimanual activities emerge early in development, as de Schonen (1977) and Ramsay et al (1979) have demonstrated.

Peters discusses the problem in terms of allocation of attention, but it is clear that this concerns possible limiting factors on the control level of motor programming function. Peters argues that if scheduling output is limited, then it might be expected that the preferred hand will tend to dominate the observed timing structure in a tapping task.

Duncan (1979), Klapp (1979), Stager and Laabs (1977), Yamanishi et al (1979) and Wickens (1976) did not report a hand dominance effect, but may not have adaquately tested for it. Certainly, Beaton (1979), and Peters (1977) both found "striking" asymmetry, and suggested that the hands interacted. When the performance of the hands in isolation is compared, Barnsley and Rabinovitch (1970) and Peters and Durding (1978) both found that the preferred hand can synchronise more accurately with a target series than the non-preferred hand. Wolff et al (1977) suggest that performance on the non-preferred hand inproved to the level of the preferred hand when the two were engaged together.

These results suggest that there are indeed restrictions on organisation. Klapp (1979) and Peters (1977) argue that only one organisational schedule can be produced at one time, and that concurrent motor activities require that different organisational schedules can be integrated into one composite schedule.

Shaffer's (1973) work on the effect of preview and the meaningfulness of information input to the skilled typist led him to conclude that a motor programme is best considered as having two temporally overlapping stages. Stage one assimilated input and converted it into a form compatible with output elements. Stage two translates those output elements into motor commands and actualizes them. The effect of skill in performance in terms of increased speed is derived from an increase in the extent of temporal overlap between the two stages. As the input is converted, the motor commands for output are being accessed from memory in parallel.

The aquisition of fluency, in this model, could be the development of more parallel processing between the control level that is assimilating data and preparing a schedule, and the motor system that is organising and effecting output.

There could be other elements in the development of skill. Lundervold (1951) found that trained typists employ fewer muscles, and fewer cells in each muscle, than relatively untrained typists. The latter also contracted their muscles more between strokes, while their finger was in transit between keys. This was simply static contraction of the muscle, hence a waste of energy.

Bernstein (1967) showed that the form of movement was a resultant of cyclical forces arising peripherally from gravity, inertia, and the surrounding medium. The motor program complements and exploits these peripheral forces. Skill, therefore, is also represented in the maximising of this exploitation, and hence the minimising of the effort required. Herrigel (1971) describes the Zen ideal that no effort at all is required, all motive force being channelled from the environment. Thus skill is also reflected in the increased utilization of peripheral forces to minimise the input of energy required.

Skill is, of course, also associated with the aquisition of new repertoires of behaviour, the knowledge of possible courses of action. At a more fundamental level, Trevarthen (1984) suggests that developing a skill may also reflect the development of new biodynamic structures, i.e., that new codes or principles of coordination may be discovered with experience. For example, Schlapp (1973), in a study of violinist's vibrato, found that training improves control of the voluntary tremor. This is not affected by loading, thus it clearly is a development of the timing function of the motor program. Reger (1932) made a similar finding. Students of the violin proved to have the largest range of rates of vibrato used, when compared with violin teachers and concert artists. However, the relationship between skill and control is not a simple one. Reger also found that the concert artists had greater between-cycle variation than either of his other two groups.

There may also be a change in the kind of information used with increasing skill. Honzik (1932) and Fitts (1951) suggest that kinesthetic cues come in to play as a basis for making and confirming responses only after some learning has occurred on the basis of exteroceptive information, such as vision. West (1967) tested this hypothesis in an examination of typing skills, and found that there was indeed a rapid rise in kinesthetic dependability from the novice stage, although this improvement reached a plateau at intermediate levels of skill.

Shaffer's model of a programmable clock, which can be set to run in periodic or aperiodic mode, has further implications for the nature of output and the nature of perception. The fact that the clock rate could be programmed by timing features which were selected from the abstract representation of the output sequence of motoric acts bears directly on the development in linguistics of Lehiste's (1977) concept of the "perceptual centre" or "centre of gravity" of words as the feature of speech by which production timing is regulated, rather than the more abstract concept of an ideal isochronic unit. This indicates that although the clock can operate in a quasi-isochronic mode, it cannot be assumed that the clock's proper rate should be truly periodic.

Marcus (1981) defines a perceptual centre as being that element which is regular in a perceptually regular sequence of speech sounds. He demonstrated that the perceptual centre location is affected by both the initial consonant duration and the subsequent vowel and consonant duration. Although Marcus was able to demonstrate that a simple model involving these two parameters could predict perceptual centre location, he argues against the efforts by Rapp-Holmgren (1971) and Allen (1972) to define the physical correlate of the perceptual centre. Marcus argues that it is pointless to attempt to determine any single acoustic or articulatory correlate of centre location, or to attempt to determine a centre at a precise point in time. The perceptual centre appears to be a property of the whole stimulus, and, according to Morton et al (1976), reflects properties of both the production and perception of speech.

This is a particularly pertinent point in an analysis of the timing and organisation of movement dynamics involved in the production of music. That is, it must not be assumed that sound onsets or offsets are the elements of the timing strategy.

There is an alternative explanation of the operation of the motor system. Kelso et al (1981) argue that the concept of the motor program cannot be used to solve the degrees of freedom problem posed by Bernstein (1967). They suggest a homokinetic theory: that biological systems can be considered as ensembles of non-linear limit cycle oscillators. Thus, they argue, there is no need to represent every detail in the behavioural sequence. Order and regularity in movement behaviour might not be due to an a priori description in terms of programs, and reference levels, where such a description is independent of and causally antecedent to the motor action, nor need representation be isomorphic. Rather, spatio-temporal organisation and the dissipation of degrees of freedom could arise as an a posteriori fact, an emergent property that is a consequence of and concommitant with the dynamical behaviour of the system.

Theories of "extrinsic" timing distinguish between the plan for an act and the executor or timing program. Kozhevnikov and Chistovich (1965), Bernstein (1967), and Lashley (1951) make this distinction quite clear. However, Shik et al (1966) state that rhythm generators are

> "temporary organisations of the spinal nervous system marshalled for the purposes of locomotion that generate rhythmic stepping movements."

That is, the rhythm generator is act-specific, and does not regulate separate classes of action. Shik and Orlovskii (1965) make it quite clear that they believe

> "there is no generator of running independent of the actually performed movement."

These theories of "intrinsic" timing imply that an act has no homogeneity or coherence at any instant in time, as there is no underlying aim to be in a succession of states. Rather, an act's coherence only emerges in its actualisation.

However, this "intrinsic" timing model, while it may be validly applied to repetitive movements such as running, is not adaquate to explain the permutations that obtain with highly skilled performance, when deviations from regularity may be required.

It is clear that when considering a skill which may involve translating a formally structured abstract representation, such as a score, into action that the action pattern must itself be represented in some abstract form in the pre-actualisation stage.

However, an integration of the model of Kelso et al with that of Shaffer is quite possible. Other workers in the area established by Bernstein agree that there must exist some hierarchic structure for the execution of motor skills. Gelfand et al (1971) state as follows.

> "In order for the higher levels of the central nervous system to solve effectively the problem of the organisation of motor acts it is essential that the number of controlled parameters not be too large and the afferentation required not too high. It is customary to call synergies, which play an important role in the establishment of such conditions, those classes of movement which have similar kinematic characteristics, coinciding active muscle groups and conducting types of afferentiation."

This implies that the properties that Kelso et al describe are in fact properties of synergies. The existence of these attributes of synergies partially solves the degrees of freedom problem for the higher organisational levels. Similarly, Fitch and Turvey (1977) propose a model for movement control that offers the possibility of a principled solution to Bernstein's (1967) degrees of freedom problem. It entails an analysis on the level of the specification the movement goal, rather than the details of muscle firings. The achievement of the defined goal must then be interpreted and actualised by a second system which is involved in the maintenance of an accurate internal representation of body-centred space, in a field parameterised by gravity. This second system is then able to mediate the achievement of a spatial goal from a range of starting positions, with the broader competence to involve compensatory shifts of other muscle groupings to allow for shifts in body centre of gravity. This proposal indicates that where the overall timing, the moment of achieving the goal, is set at a level closer to immediate consciousness, the internal timing of the movement is determined by this second system.

The dissipation of degrees of freedom via the dynamic organisation of the system is thus quite compatible with there being higher levels of abstract representations of courses of action. The dynamics inform consciousness of the range of possible action, and the consciousness develops (in the development of skill) towards the maximum integration with and exploitation of the system dynamics of the organism in the appropriate environment, for example, that of a keyboard.

The only real distinction that remains between theories of "extrinsic" and "intrinsic" timing is that of emphasis. As Fowler (1977) puts it, that the role of the central decision maker is organisational rather than executive.

The overall integration of this system can be seen in the fact that human beings are highly skilled in coordinating posture and movements to fine details of perceptual information (Lee and Young, 1985). It can also be seen in the fact that actions are identified in consciousness with their consequences. This is true of all types of action and levels of skill, with the possible exception of the early stages of aquisition of a skill, when one becomes aware of the actions themselves in establishing the connections between a specific action at a particular time and its result.

Trevarthen (1984) points out that this relationship is a dynamic dialogue. The perception of an object is conditioned by the ecology of the stimuli. That is, perception is, at one level, in terms of opportunities for interaction, which Gibson (1977) termed affordances. The other direction of the dialogue is represented by selective attention and action, with the current priorities of the organism influencing the interaction with objects.

With the human organism, this model must be enlarged to include the concept of shared concepts. That is, the human ecological environment must include a cultural and interpersonal dimension. This level of awareness would allow a matching of information about the movement structure of another person to the observer's own motivational structure, thus allowing the attribution of intent and awareness of the other's motivation. Lehiste (1973) relegated stress timing of speech to the domain of a perceptual phenomenon. However, Fowler (1977) points out that stress timing is demonstrably controlled by the talker. Allen (1968, 1972) and Fraisse (1974) found that subjects could anticipate the stress beats in spoken language. The temporal patterning of language is therefore an intersubjective phenomenon.

This extension into the realm of intersubjectivity is necessary in order to explain the accounts of conducting discussed in the next section of this chapter.

Summary

There are three main elements in the organisation of movement. The first is the intention. The second component is the control level. It is here that the sequencing of movements is organised. The third component is the performance grammar. This is a set of rules for the marshalling and coordinating, and finally effecting of the motor commands. Kornhuber (1974), and Shik and Orlovski (1965) have provided evidence that this latter function is probably represented in the cerebellum and spine.

The task of timing involves all elements, with distinctive contributions. The first contributes the coarse sequencing of events. The control system has an abstract, stochastic output clock. This sets the targetting goals to which the clock at the motor system level does the countdowns. This latter level clearly incorporates a timekeeping function. As movements have temporal goals, the timing is a determining parameter of movement. The clock at this level is thus relatively fixed, and can be considered to be a 'real' clock. More than one clock may be operating at this level, as individual motor units may be timed separately, within limits. These limits are set by the output schedule train length, which is set by the control level, and by the degree to which the clock bases interfere with each other.

The relationship between these two levels is highly interactive and dynamic, as evidenced by the existence of units of action. The control level generates the necessary information in streams which may be stored in parallel, maintaining a separate identity (subject to the restrictions mentioned above), and output together (for example, to different hands). This means that there must be a FIFO sequential access buffer between the two stages, in which the arrays could be stored. The representation of information in these streams appears to be in ratio, or relative, not absolute form. That is, it is stochastic.

The development of skill reflects four processes. Firstly, increased processing in parallel at the various levels. Secondly, the development of new relationships between levels of planning and programming, i.e., the development of new biodynamic structures. Thirdly, the increase in the repertoire of routines available to the intention and control levels. Fourthly, the increased exploitation of peripheral forces to reduce the input of energy required in the effecting of output.

Finally, the phenomenon of intersubjectivity appears to be mediated through an extrapolation to the level of planning (a person's intentions) from the level of programming (a person's actions).

Part three. The role of the conductor.

One of the principal aims of this thesis is to investigate the principles of communication of timing information in music. One aspect of the role of the conductor is to perform this function, and to establish the common ensemble that allows the disparate instruments of the orchestra to achieve a mutually coordinated timing structure. The conductor is therefore a suitable candidate for study, and chapters two to four focus on the communication between conductors and musicians.

In order to justify this focus, and to provide evidence for the above statement on the functions of the conductor, this section will briefly review the historical background and evolution of the role. The direct quotes from musicians are all contained in Previn (1979), and in the other references cited in this section.

The role of the conductor antecedes that of the contemporary orchestra, dating back to Hellenic Greece. The chorus in the Greek theatre were kept in time by a member who would stamp his foot on a stool, wearing a reinforced boot to amplify the sound.

In the thirteenth century, one of the singers in a chorus would keep time by tapping his hand on the music book. By the fifteenth century, the mode of communication had become more sophisticated, with time being beaten in the air with a sheet of rolled parchment called a sol-fa. This was a more abstract representation of the beat, as there was no actual sound present. In the Musicae Activae

Micrologus, published in the sixteenth century, the lead singer is directed to make motions in the air

> "according to the nature of the marks which direct a song according to measure."

However, as late as the early nineteenth century, many leaders still employed sound as the medium, and would stamp on the floor, clap their hands, or bang a desk or music stand with a piece of wood or rolled parchment. Darnton (1940) quotes from 'A Comparison between the French and Italian Musick and Operas', published in 1709.

> "Some years since the Master of the Musick in the Opera at Paris had an Elboe Chair and Desk plac'd on the Stage, where, with the Score in One Hand, and a Stick in the other, he beat Time on a Table put there for that purpose, so loud, that he made a greater noise than the whole Band, on purpose to be heard by the Performer. By degrees they remov'd this Abuse from the Stage to the Musick Room, where the Composer beats the Time in the same manner, and as loud as ever. The same was observ'd in London six or seven years ago, but since the Italian Masters are coming among us, and the Opera's have been introduced, they have put a stop to that ridiculous Custom, which was founded more upon an ill Habit than any Necessity there was for it, as doing more harm than good, for the Opera's are better Performed now without it than any piece was formerly; because the Eye was too much Distracted, being obliged to mind the beating of the Measure, and the Score at the same time; besides, it kept the Singer and the Player in too much Subjection, and Fear of errórs, by which means they were depriv'd of the Liberty, so absolutely necessary to Musick, and which gives a Strength and Spirit to the Notes."

Note that the removal of the conductor to a backstage room, in the attempt to muffle the bangs, means that the communication of the beat must have been entirely aural, with no visual correlate present. The question of the difference that the mode of communication makes is dealt with in chapters two and eight.

In Germany, the norm was for the band leader to keep time by thumping the floor with a heavy stick. This method finally fell into decline after 1687, when the French composer Lully, conducting one of his own compositions, missed the floor and hit his foot. The resulting oedema developed into gangrene, and Lully died of his injury.

Gradually the floor pounding staff was replaced by the baton, and the medium of communication became predominantly visual. Some early batons still reflected their ancestry. Berlioz used a heavy oak stick, Gluck used a violin bow to conduct. The modern lightweight baton familiar today was introduced by Spohr in 1820 to conduct one of his symphonies, and rapidly became popular. Schumann found it difficult to adapt to such an insubstantial stick, and his baton kept flying out of his hand into the orchestra until he had to resort to tying it to his wrist with string so that he could rapidly retrieve it. Spohr is also generally credited with being the first conductor to leave the keyboard and stand in front of the orchestra. He could therefore be considered to be the innovator of the role of conductor as we know it today.

The role of the conductor expanded to include functions previously associated with the band leader: the details of rehearsal and the interpretation of the music. Different conductors vary in the relative importance they attach to these functions.

Standard practice today is to divide the violins into two sections, corresponding to soprano and alto voices. The first violins carry the main melodic line. The first violinist, usually seated immediately to the conductor's left, is often the leader of the orchestra. This role normally includes the liason between conductor and orchestra, playing violin solos, ruling on matters of bowing and phrasing, and being responsible for the internal administration of the orchestra. This means that, as Ronayne (first violin, LSO) puts it,

> "It takes a lot of tact to lead. In England...our orchestras have to hire parts, which the leader has to re-bow each time, scrubbing out the amazing aberrations of the man before. Now the tradition here, at least with the great conductors, is that they don't interfere. I never remember Beecham or Kempe saying anything about bowings. The leader and the string principals are the experts and it's up to them to get it right. But...the conductor Tibor Paul, a Hungarian ex-clarinet player, thought he could do it all..."

Nutt (second violin, LSO) adds the following.

> "With Stokowski you did as you liked, so long as it sounded nice...our bowings were so disciplined under Barbirolli, everything was very carefully worked out...if he said 'at the point', he wanted it in the last inch..."

The role of leader is also descended from the same root as that of the conductor. Before the nineteenth century, the principal was the conductor, except in the theatre or church. The German word for the principal violin is still Konzertmeister. Starting, stopping, tempo, rhythm, and dynamics were all controlled by the principal. As Howes (1942) puts it

> "(the principal's) position was..like that of the stroke of an eight-oared racing crew."

In opera or oratorio, overall control of the performance resided with the player of the harpsichord or piano, who controlled the singers, and the principal's task was to keep the players in line with the keyboard. Throughout the seventeenth and eighteenth centuries timekeeping was normally done from a keyboard. The accompanist or 'continuo-player' was often the composer, and, as rehearsals were uncommon, was often the only person present who knew how the piece should sound. He normally played from a figured bass, the lowest line of the music. If the performance seemed in danger of losing the beat, the continuo-player would sacrifice the right-hand part, continue to play the bass line with his left hand, and beat time with his right. Both Haydn and Mozart conducted from the keyboard, as Ashkenazy does today.

The particularly British tradition of working without rehearsals continued into the inter-war period of this century. During part of this time the deputy system was prevalent. This was a kind of job-sharing system which meant that the player who was present at rehearsal might not be the player who gave the first performance. One visiting conductor from the Continent was sufficiently disturbed by the fact that about half the orchestra had changed at each rehearsal to make a point of conspicuously congratulating the principal double-bass player, who had remained throughout the series of rehearsals, only to be answered

> "That's all right, sir, but I shan't be coming to the concert".

This state of affairs led to some slackness in excecution, but great agility in performance and a high degree of proficiency in sight reading, reputations which remain with some British orchestras today. Berlioz commented as follows.

> "It's the English who have brought the art of speeded-up rehearsing to a degree of splendour unknown to other nations."

The approach was re-examined after the first visit of the Berlin Philharmonic in 1927 demonstrated what continuity and disciplined precision could achieve. However, this cavalier British attitude to rehearsals was partly instrumental in the development and codification of stick technique, as accuracy in communication then became crucial.

Berlioz formulated one of the earliest sets of principles of conducting in 1850. According to Spence (1979), he was stung into doing so by a succession of inept conductors who mangled his compositions, culminating in a performance of his Requiem in 1837 when the conductor, Habeneck, stopped conducting in the middle to take some snuff. Berlioz threw Habeneck aside and completed the performance himself, then drew up his set of rules in an attempt to prevent reoccurrences.

It is Nikisch, however, who is generally credited with the development of formal stick technique. Boult was the first to formulate the principles in English.

There is some difference of opinion as to the purpose of the baton. Generally, however, there is agreement that it aids greater visibility and permits finer nuance than the unaided hand. Boult compared the stick to an extra articulation of the arm which served as a gearbox, allowing a wrist and baton movement to substitute for a whole forearm movement. He then developed a model of hierarchical movement organisation, with pianissimo conveyed with the baton tip, piano passages involving the hand and wrist, forte involving the elbow, and fortissimo the shoulder.

Wood insisted that the baton be white for maximum visibility, so that it could be monitored with peripheral vision.

There is also general agreement that the point of the baton conveys maximum precision, as the following quote from Howes (1942) makes clear.

> "Quite minute movements can be made clearly visible by the travel of this long extra arm of the body and the greatest precision obtained....the point of the stick is the ideal medium for minute and precise indications of speed, attack, and the finer gradations of tone."

Boult states that the point of the stick is the-

> "..focus of the whole contact between the conductor and the orchestra."

Howes then makes the general comment that conducting works by suggestion, pointing out the limitations of the actual information in these words.

> "Conducting is in fact making gestures with a little stick."

On the other hand, MacGuire (first violin, LSO) argues as follows.

> "Sometimes I'll be asked 'well, how do you follow a conductor?' Have I ever looked at a conductor's beat in my life? I'm not sure...one looks at the conductor, the whole man. The message comes from the balls of the feet, right through to the top of the head, not just what he does with his hands."

Scherchen, in his 'Handbook of Conducting', argues that a conductor must first aquire a grounding in theoretical and practical musicianship. Then the focus should be on developing a clear style with the baton and memorising the score. Gattey (1982) cites von Bulow as saying

> "You must have the score in your head, not your head in the score."

Holmes (1982) notes that Schippers had more than eighty operas in his repertiore, all of which he conducted from memory.

The extent to which a score can be memorised obviously varies. Even among these conductors who conduct from memory, few have the eidetic memory that Toscanini was reputed to posess. Toscanini was once observed to conduct a performance of Tosca with a score in front of him. During the intermission, one of the audience asked one of the musicians if Toscanini's memory was failing at last. "Oh no" came the reply, "the maestro is just running through Tannhauser for tomorrow night."

Toscanini was once approached by the second bassoonist, who informed him that a key was broken and that he would be unable to play his lowest note. Toscanini thought for a minute, then told the musician that he did not play that note in that night's concert. Shore, in his 'The orchestra speaks', suggests that Toscanini was forced to develop this memory by his short-sightedness which meant that he could not rely on a score.

At the other extreme, there is the story of the conductor who had given several performances of a work by Stravinsky, before it was discovered that the trumpets had ten bars left out of their parts and had been coming in that much too soon without being spotted.

Glover, in her BBC2 series 'Orchestra', describes the role of the conductor as follows. Firstly, the conductor must grasp the overall architecture of the piece, so that he can give tempi and entries decisively. Secondly, he must be familiar with all the instruments, so as to be able to give informed comment on interpretation. Thirdly, he assumes responsibility for the interpretion of the score.

Thus the primary roles of the conductor are coordination and interpretation. Generally, the more professional the orchestra, the less the conductor has to do with timekeeping. During a Mehta masterclass on conducting in 1983, as an object lesson, Mehta stopped one of his pupils conducting during one of the most rhythmically difficult passages of Stravinsky's Rite of Spring. The orchestra, the Israeli Philharmonic, faltered momentarily, then regrouped and played successfully through to the end and finished together. Mehta did point out that this could not have been done as successfully by a lesser orchestra. Some conductors, however, such as Sanderlink, do restrict themselves to timekeeping, and allow the players to provide the expression, so this is not a universal rule. Mengelberg and Wood both had each musician's part notated with the phrasing and dynamics, so that they were relieved of some of the burden of communication of interpretation.

Sometimes the two roles can conflict. One LSO musician commented as follows.

> "I'd never played (Don Juan), though I'd studied it and practiced my part. Well, in the beginning the strings sweep up, then there are the basses and the brass trombone, which has the phrase on the beat, and it has to be there. Von Karajan made some loose, ethereal movement- which the strings understood and first fiddle led them up the sweep. But I could'nt see or feel a downbeat at all- he just had his arms in the air, he was'nt going to beat it like a bandmaster- and I missed my entry." (Karajan does not generally give entrance cues.)

Barbirolli would make a deliberately confusing motion with the baton while conducting Verdi's Requiem, to try and make the cellos play an ethereal sound without a clear onset.

Some conductors are better at one aspect of the job than at other. Kettel (timpani and percussion, LSO), says of Boulez

> "he could do a three over sixteen and a seven over sixteen and do an eight against it exactly, but when it came to a single, rigid tempo, he did'nt have natural time- he'd be no good playing drums in a rock group."

Some musicians prefer clear timekeeping, others look to a conductor for inspiration. Pay (clarinet, LSO) comments as follows.

> "It's hard to know what importance to attach to conducting technique, to a precise beat. Remember Furtwangler- conducting is so much a question of musicality and

> personality...in a good orchestra, once you know the kind of gestures a man uses, you make adjustments for personal eccentricities. As someone said of Reginald Goodall at the National Opera, the whole performance hung upon some player making a decision in every bar. His lack of clarity put the responsibility right in the lap of the orchestra, yet they were prepared to play for him because he was dealing at a higher level. He was saying what happens when you've got all the notes together but he rather left it to the band to get them....for the great chord in the slow movement of the Eroica Kempe ended the downbeat with a large judder. No-one quite knew where to play. So our new principal cello piped up 'why don't you just go like that?' giving a firm, clear beat...Kempe just smiled and did as requested. But in the concert he was back to his old, juddering beat, and he got the effect he wanted. We played it together anyway."

Lang (trumpet, LSO) adds the following.

> "(Previn) cuts corners, a bit casual, but still the orchestra plays well, far better than for a fellow that lays down the beat rigidly...Sargent did that. He looked marvellous and sounded terribly disappointing. Now Barbirolli, he'd been a cellist, and he was for the strings, all those sweeping gestures were for the bow, which was no help to the brass. But when you got used to him, you knew where to put the notes...it's a great mystery, conducting."

Ashkenazy puts the distinction between technique and inspiration into context.

> "To have a very good conducting technique is wonderful of course, but attaching too much importance to the technique can be a mistake if it becomes an aim in itself, which occasionally happens. What's the point of standing there with a magnificent technique if you are not communicating the fundamental thing?"

Ashkenazy also points out that there are occasions when the orchestra is best left unconducted. During a soloist's performance, the conductor must take time from the soloist and relay it to the orchestra. It is sometimes easier for the orchestra to take time directly from the soloist.

It should be clear that the ability of some orchestras to self-regulate without reference to a conductor should not be underestimated. Obviously, the level of professional skill and the degree of familiarity with the piece are critical. The LSO and the Vienna Philharmonic can play many of the standard classics in their repertoire without a conductor. With groups of that calibre, the conductor's task may not be to do basic timekeeping as much as to impose their "vision" of the music by making the orchestra get out of the established routine, to vary the pace and dynamic and thereby keep the music fresh.

Mehta believes that the first duty of a conductor is to establish ensemble, and the the details of interpretation come later.

> "You don't always have to stop to make small rhythmic corrections. Try and correct 'in flight' if you can. You can do this with a good orchestra. Only stop if you have to make some major, organic, change. Give more beats. When it goes by itself, then you don't have to..until then, help them..conducting is communication."

Micci (first violin, LSO) agrees with this approach.

> "Conductors talk away, I don't know why they persist in it. A musician, he does'nt need to talk, he can express what he means with the baton, with his arms and body."

McElheren advises that subtle nuances are not communicated with the baton, but with the expression on the face or a half-shrug. Another LSO player adds.

> "Beecham did everything with his eyes. Wherever you were sitting you had this wonderful feeling of contact with

him- you personally, even at the back of the seconds. But you can sit under the nose of a bad conductor and you get nothing, nothing at all."

Ashkenazy, similarly, has stated that-

"The definition of a good conductor is that he conveys the music to you. This can be done with anything- even with the eyes."

Boult's famous comment must be relevant here.

"The object of technique in all art is the achievement of the desired ends with the greatest simplicity and economy of means."

There still remains, however, an essential mystery. The last comment goes to Civil (horn, LSO).

"In concert, Boulez goes twice as fast, a mad scramble, because he loses control of what his arm is doing. He uses the whole arm (Boulez often does not use a baton), which generates a terrific momentum as he tries to get all the beats in. But there is no necessity to organise music to such a degree. Boulez seems to feel that if he does'nt give the beats nobody can play, which is nonsense. Well, that's the mystery- how did Furtwangler get anyone to play then? or Klemperer, who was such a wreck he could'nt hold a baton? I remember Klemperer hobbling in on a stick, yet managing to indicate the first beat of Beethoven Five before he was even on his stool. Goodness knows where the downbeat came from, but we came in perfectly."

Part four. General Methods.

The details of the experimental methods are given in each chapter. However, there are some features that are in common to chapters two, three, and four. These are the following.

Recording apparatus and analysis procedure

The first common feature concerns the recording of real-time data and the first stage of the analysis procedure. All the data in this section was recorded using the Selspot movement monitoring system. The general principles of operation of this system are as follows.

The system comprises two cameras, up to twenty light-emitting diodes (LED's), an LED control unit, and the main control unit. The cameras each produce a pair of signals that correspond to the coordinates of the image of an infra-red LED in the camera's focal plane. The resolution is 1mm per metre of field of view. Up to twenty LED's, which are as small as a map pin head, may be attached to points of interest. These might be, for example, limb joints, individual finger joints, or external objects controlled by a subject. Each LED is switched on in turn for 50 microseconds every 3.2 milliseconds, and its image coordinates are digitised. The stream of digitised coordinates may then be transmitted to a computer for storage. The main storage medium used was a series of RK05 disks, mounted on a DEC PDP11 minicomputer.

The Selspot system at Edinburgh has been modified by D. Young so that an analogue signal (from, for example, a microphone or a foot switch) can be connected to the digitising equipment. This can then be recorded synchronously with the movements of the LED's.

When setting up an experiment, a real-time display of LED's may be presented on an oscilloscope. This allows positioning of cameras and subjects. It is possible to specify the numbers of cameras and LED's to be used, and whether the sampling interval should be 3.2ms or some multiple of this, so that irrelevant data is not recorded. The duration of each recording is specified, and recording is started either from the keyboard or with a separate switch.

The system can rapidly generate vast quantities of data. The initial analysis must therefore be flexible, as it is necessary to explore possibilities before investing time in a detailed processing of any particular sequence of data points. The first stage of the analysis thus depends on a program, running on the PDP11, which allows the recordings to be played back as if they were films. The LED's are shown on the CRT display monitor. Each LED may be marked, omitted, or joined to other LED's with lines. The time series may be played back at any speed, repeated in part or whole, run forwards or backwards. Multiple images of successive framess may be superimposed, the increment between points selected may be determined, and hard copy obtained. The program is highly interactive, which makes it possible to assess the quality of a recording and to choose sections for more detailed analysis.

The next stage is usually to look at the variation of particular parameters in time, such as the timing of changes in the movement, or the variation of this over conditions. D.Young, who developed the first stage programs, also developed the second stage programs. These second stage programs allow display of high resolution graphs of the time course of any coordinate, the distance between LED's, angles subtended between an LED and two others, or the angle between two LED's subtended at either of the coordinate axes, all as seen by the camera. These time series may then be further processed in a variety of ways; smoothed, differentiated, squared, added, Fourier transformed, etcetera, all under interactive control, and hard copies obtained at any stage. There is a cursor that allows accurate identification of times of significant events.

Numbers of subjects

The second feature in common to the different series of experiments concerned the numbers of subjects. The comments here also pertain to chapters six to nine. The design of the study was to record detailed data and reports from relatively small numbers of subjects, rather than extensive but necessarily relatively shallow data from larger numbers of subjects. This was for two reasons. Firstly, only very detailed data would suffice to answer the questions posed, and this necessarily placed restrictions on the numbers of subjects that could be processed. Secondly, because the commonly held belief that one can generalise from the basis of a sufficient number of subjects to the general population is actually incorrect. This limitation arises from special problems inherent in small sample statistics.

The explanation is as follows. Gentile et al (1962) noted in their field (applied behavioural studies) the "assumed inapplicability" of statistical techniques to individual cases or small numbers of subjects, and proposed the use of an analysis-of-variance (ANOVA) model for analysis of data gathered with the reversal design using a single subject. Their critical assumption was that successively obtained observations that could be obtained within a treatment condition may be considered to be independent of one another: a seemingly critical assumption for the valid application of the ANOVA model.

There is considerable dispute as to whether this assumption is justifiable. Kratochwill et al (1974) performed an experiment in which they demonstrated the rather extreme degree of dependence seen in successively obtained observations of exactly the same type analysed by Gentile et al. Hartmann (1974) describes two ways in which the nonindependence of successively obtained observations within treatments would be expected to produce a positive bias, and another factor that could well produce a negative (conservative) bias if the Gentile et al procedure is used. Thoresen and Elashoff (1974) generally support Hartmann`s criticism. Keselman and Leventhal (1974) also make the point that nonindependence of successively obtained observations is the critical problem not adaquately dealt with by Gentile et al.

The consensus of these authors is, then, that the only possibility of application of ANOVA procedures with N=1 data would be if the condition of sequential independence is met. Hartmann suggests that this might be partially achieved by maintaining each condition long enough to obtain several "stable" observations (he suggests twelve), then using only these data in the analysis.

However, Edgington (1967) suggests that provided that the order in which the experimental treatments or conditions are applied is genuinely random, then it is in fact perfectly possible to assume sequential independence and the absence of systematic order-effect type bias. Edgington then goes into some detail on the value of N=1 studies. Starting with a discussion of Dukes's (1965) paper, in which Dukes gives a number of examples of published research to effectively demonstrate the value of N=1 studies, Edgington points out that the reason for the relative paucity of such studies was perhaps because editors expect experimental results to be evaluated by statistical tests, and there was no clear guide for the application of a statistical test to one subject.

Probably the main reason why books on statistics tend to ignore the problem of the application of significance tests to such data is that one subject studies cannot provide any estimate of the population variability and consequently there is no basis for statistical inference about the population from which the subject was selected.

While the fact that you cannot statistically generalize to a population of individuals on the basis of measurements from only one subject is incontrovertably correct, it is also correct that you cannot statistically generalize to a population from which you have not taken a random sample. Edgington notes that this in fact rules out statistical generalization to a population for virtually all psychological experiments, those with "large samples or small".

It is still possible to test hypotheses in the absence of random samples, but the significance statements are restricted to the domain of the subjects actually used in the experiment. Generalization to other individuals can only be on the basis of presumably logical, but not statistical, considerations. Having outlined the problem, Edgington goes on to redress the lack of a coherent set of guidelines for the statistical evaluation of N=1 studies by providing a rationale for testing the significance of differences between treatments or conditions for an individual. The hypothesis-testing procedure he proposes differs from the conventional random sampling approach to hypothesis testing in several respects. Essentially, it tests the null hypothesis of identical effects within conditions, not the null hypothesis of identical mean effects. It does not involve assumptions of random sampling of a population of individuals or a population of responses.

The only real alternative to Edgington's solution will evolve through the development of more sophisticated time series analysis techniques.

Michael (1974b) makes the most fundamental point that descriptive and inferential statistics generally, and significance levels in particular, are essentially judgemental aids, simplifications or condensations of data which it is easier to assimilate than raw data. Significance levels are not always a complete basis for any kind of judgement. For example, there is no justification other than convention for the .05 or .01 levels. The struggle to achieve significance levels, Michael adds, is sometimes a substitute for achieving proper experimental control. Thus he resisted the attempt by Gentile et al to introduce a more powerful statistic to N=1 studies, on the grounds that it is more relevant to attempt to achieve a clearer differentiation of result profiles through better experimentation rather than to resort to more powerful statistics, often in a post-hoc attempt to salvage some publishable results from insufficiently clear data.

With regard to the N=1 controversy, Michael (1974a) points out that when the assumptions underlying a statistical procedure cannot be met, the procedure is not necessarily useless: provided that the probability value is viewed as a rough approximation the test may be used.

The subjects in these experiments were selected on the basis of their skill, and all were final year undergraduates or postgraduates at the Department of Music at Edinburgh University. This by definition restricted the potential sample pool and ensured non-randomness.

Thus all the experiments reported here are concerned with the differences between conditions obtained by individual, highly skilled subjects.

Chapter Two

The Interaction of Multiple Sources of Timing Information.

Abstract

There are various sources of information on timing available to the musician. These are, firstly, the ensemble of the group, secondly, the conductor, thirdly, the score, and fourthly, the musician's internal timing. Their contributions and interactions are analysed and described. Other factors considered included tempo, beat, and replication. When no score is present, the minimal adaquate model (the least number of factors that adaquately explain the observed variance) is an ensemble * conductor interaction which varies systematically by tempo, with ensemble the most powerful factor. With a score present, ensemble alone is the critical variable. This strongly suggests that the normal role of the conductor is to provide general, rather than precise, timing information although he can assume the latter function when necessary. Precision is normally derived from ensemble.

Acknowledgements

I would like to especially acknowledge the help of Peter Fisk and Frances Provan of the Department of Statistics in the analysis.

Introduction

There are four main sources of timing information available to the orchestral player:

(1) the other player(s)

(2) the conductor

(3) the score

(4) the player's own sense of rhythm

The aim of this experiment was to assess the relative contribution of each, and the level of timing accuracy achieved. The questions were as follows.

Firstly, if musicians play in time, some component of their output must be synchronised. Are they synchronising with each other or with the conductor?

Secondly, if the players can neither hear nor see each other, but can see the conductor, will they utilise the same information parameter to time their actions, and will they use the information in the same way? In other words, will they perceive the same start time and tempo?

Thirdly, is the presence of a score a sufficient substitute for either the conductor or the ensemble?

Fourthly, can a player's internal sense of timing compensate for the absence of information from the other players, the conductor, and the score?

The first, second, and third sources of information were controlled directly, by their presence or absence, while the fourth was studied indirectly by comparisons across repetitions and within trials.

Methods

Subjects

There were three subjects in these experiments. The conductor, G.T., and two percussionists, D.R.and P.C. All were final year or postgraduate students at Edinburgh University's Department of Music.

Data Recording

A Selspot movement monitoring system was used to record the. position of light-emitting diodes (LED's) attached to baton and drum tips. A PDP11 minicomputer was used to store the data. Recording speed was 1 frame per 3.2 ms.

Position of subjects

The photographs in appendix two show how the conductor and musicians were placed with respect to each other. G.T. is on the left in both photographs. D.R. is the left, P.C. the right of the two percussionists in photograph 2.1 , D.R. is the further away and P.C. the nearer in photograph 2.2.

Camera one recorded the conductor's baton. The baton was 8.5 feet away from the camera, and its tip moved in the fronto-parallel plane. The field of view included the entire baton trajectory. The players sat 1.5 feet behind their drums, there was 11 feet between them and the conductor.

The two drums were 3 feet apart, the drummers sat 4 feet apart.

They were angled toward the conductor so that both drumsticks would remain in the field of view of camera two. This second camera was behind the conductor, aimed over his head at the drums. The drumstick LED's were 10.5 feet away from camera two in the fronto-parallel plane.

The percussionists' music stands were set slightly off to the outer sides, so that they did not occlude the LED's.

The positioning of the conductor, percussionists, and music stands was in no way unusual.

Experimental Design

The experiment varied the information available to the percussionists in the following way.

Main parameters

(1) Ensemble. The players played under normal conditions, or were sight and sound screened from each other, while retaining a good view of the conductor. This screening was effected by (a) introducing a standing screen between the players, and (b) having the players put on headphones and subjecting them to a level of white noise which prevented each from hearing the other but allowed each to hear himself.

(2) The conductor. He conducted normally, or gave the first beat only (to get the players started), then stood with arms folded.

(3) The score. The players played a set piece with a score, or

played a series of three equispaced taps without a score. The set piece was an excerpt from Bartok's Konzert II fur Klavier und Orchester, U.E.10995. A copy of the excerpt is in appendix three. It consists of first and second timpani parts. The second drum has to coincide on six beats, and these points were selected for analysis.

Secondary parameters

(4) Tempo. The three tempi employed were prestissimo, moderato, and larghetto. Tempo could only be varied in the no-score experiment, as the Bartok piece had a time specified. The analysis was run using the nominal set tempi. The use of the actual tempi, calculated from the inter-tap-intervals, was found not to significantly affect the results.

(5) Replication. Replications were run in both the score and the no-score conditions. There was a logistical limit imposed by the size of the data files. Since the no-score series included the tempo factor, it proved impossible to run as many replications each condition, or to record as many beats in each, as more trials had to be run overall. This means that the design is not balanced over the and beat factors. There were three replications in each of the no-score series conditions, five replications were run in each condition in the Bartok series. In total, there were thirty-six trials in the no-score series and twenty trials in the Bartok series.

Recording Procedure

When the subjects were ready, the Selspot recording apparatus was started. A short tone signalled that they should start playing. Each Bartok series recording lasted for 15.6 seconds, each no-score series recording lasted for 5.7 seconds.

Statistical Analysis

No technique currently exists for performing comparative analyses of time series format data with an experimental design imposed. The best available procedure was firstly, to reduce the number of data points by selecting those of particular importance, then secondly, to do a multi-way analysis of variance (ANOVA) of the resultant data set. The data points selected were (a) the impact times of the drumsticks on the drums, and (b) the Y-axis minima of the baton trajectories, which were discovered (see chapter three) to represent the conductor's beats.

Table one gives a summary of the variables.

Table one

Factors and dependent variables

Series	Factor and number of levels						
	Conducted?	Ensemble?	Tempo	Replicate	Beat	Score	Total
no-score-	2	2	3	3	3	N	108
Bartok -	2	2	-	5	6	Y	120

There were two dependent variables. These were:-

(1) The difference between the drum impact times, in ms. The second drum part times were subtracted from the first part times.

(2) The difference between the conductor's beat and the first part drummer's impact times. The impact times were subtracted from the baton minima.

Statistical modelling

The ANOVA was calculated using a statistical package called GLIM (Generalised LInear Models) Release 3 (Baker and Nelder (1978)). In order to understand the procedure followed, and the meaning of the terms, it is necessary to explain the special features of this ANOVA.

A model is a combination of factors and factor interactions which is a reduction or idealisation of those measurements present in the actual sample, but which subsumes a satisfactory proportion of the total variance observed in the actual sample.

There are two strategies for developing the most appropriate model. One can start with the single factors in the model and successively introduce the interactions between the factors. This is the approach one is obliged to adopt when there are five or more factors. Alternatively, one can start with all the data and remove interactions, starting with the most complex and progressively simplifying. The latter strategy leaves no large interaction untested, in this sense it makes fewer assumptions about the data. This "stepwise-down" or "backward elimination" procedure was therefore generally adopted, though in practice it is necessary to use elements both of a stepwise up and of a down strategy, starting with the saturated model (each level of every factor interacting with every other factor) and experimenting with permutations of interactions, taking out the least important and restoring those that become important. At the end of each stage the least important variable is dropped out, importance being assessed by the t-ratio which can be calculated from the estimates (of factor level or of one factor level's interaction with another) and standard errors (S.E.'s). This is not a formal test, but it measures whether the estimate level is significantly different from the first level of that factor (which is used as the zero reference point). This indicates when factor levels (or levels of interactions) are sufficiently far apart to make a difference to the model. The elimination of variables continues until the point before that where the residual sum of squares (RSS) exceeds the upper bound for an adaquate subset. For example, if on testing there proves to be no difference over the categories of some stratifying factor, then the model can be collapsed over those strata and that complication removed. Of course, premature aggregation over strata can introduce spurious correlations, or omit important factors. This is why the "backward elimination" approach must generally be used.

Note also that with non-linear regressions, the problem is to determine the values of the explanatory variable for which a significant difference between the means can be asserted. This arises with the Tempo factor if it is treated as a continuous variable.

More formally, any model with an F ratio more than the critical value for the RSS is adaquate in the sense that we cannot accept the hypothesis that the different levels of the factor have the same mean.

The F ratio is calculated from:

$$F = \frac{\text{Factor interaction S.S.} \;/\; \text{No.parameters estimated}}{\text{Residual interaction S.S.} \;/\; \text{No.parameters left unfilled}}$$

Thus models including a crucial factor are adaquate, those models excluding it are not. The simplest model uses only the crucial factor(s) and interaction(s). Such a model, which is itself adaquate but for which no submodel is adaquate, is called the "minimal adaquate" model.

There may be more than one minimal adaquate model, sometimes involving quite different variables with corresponding different interpretations. The final selection is on the grounds of parsimony. The justification for this is that "entia non sunt multiplicanda praeter necessitatem" (William of Ockham, 1280-1349).

Finally, three notes of caution.

(a) In non-random data such as we have here, it is inappropriate to attribute causality to the observed correlations.

(b) The paucity of the data means that results offer indications rather than firm directions.

(c) In translating back into the musical situation, there is a certain ambiguity as to attribution of error. For example, a diminishing discrepancy between the players' taps could equally well represent one player being initially early and consistently slow, or the other being initially late and consistently fast.

Table two contains the symbols for different types of interaction.

Table two

GLIM symbols

Factor interactions
(1) + = Main effect terms. For example,
Ensemble+Conductor = the summated variance
subsumed by these two factors independently.
(2) . = Interactions. For example,
Ensemble.Conductor = the amount of variance
subsumed by the interaction of these two factors.
(3) * = Full model (main effects and interactions).

All values given in tables, figures, etc, are in ms.

Results

The results of the no-score condition will be presented first, then the results of the condition with a score.

No-score series data

Main Factors

Ensemble

This was the most influential factor of all. Players' beats were further apart when the players were separated. This is shown in figure 2.1. The effect is influenced by other factors, principally tempo, and interacts with the conductor factor. A comparison of figure 2.2 (showing the average differences between the taps in the ensemble and conducted condition) with figure 2.4 (no ensemble, conducted) shows the increase in the range (over tempo, by beat) when there is no ensemble. The difference is much clearer when figure 2.3 (ensemble, no conductor) is compared with figure 2.5 (no ensemble, no conductor), which shows the effect of the loss of ensemble when the conductor is not available as an alternative. These two comparisons together show not only the effect of ensemble, but also the interaction with the presence of the conductor and the tempo factor. Note that figures 2.2 to 2.5 show the average differences between the drummers for each of the conducted and ensemble conditions, while figures 2.7 to 2.10 show the actual differences for each trial in the same conditions. Figure 2.11 shows the individual effect of the loss of ensemble, and figure 2.12 the effect of the loss of conductor on the average absolute differences between the drummers, by tempo.

The conductor

(a) The effect of the conductor's presence is to reduce the average difference between the players, and thus the variation in that difference over other factors. This is shown in figure 2.6. There is one exception, at larghetto when the players are together (this can be seen in figures 2.7 and 2.8). Here, the "loss" of the conductor actually reduces the maximum range by 40%. This, however, is due to just one anomalous trial (the second replicate) in the ensemble and conducted condition, which inflates the maximum range at larghetto, so this exception should not be given undue weight. When the players are separated but conducted, the overall range is belied by the narrow band of difference within which the players finish on the third beat. This can be seen in figures 2.9 and 2.4. This strongly reinforces the conclusion that the conductor does have a distinct effect on the timing accuracy. This can be seen in table three.

Figure 2.01
Average absolute differences between drummers

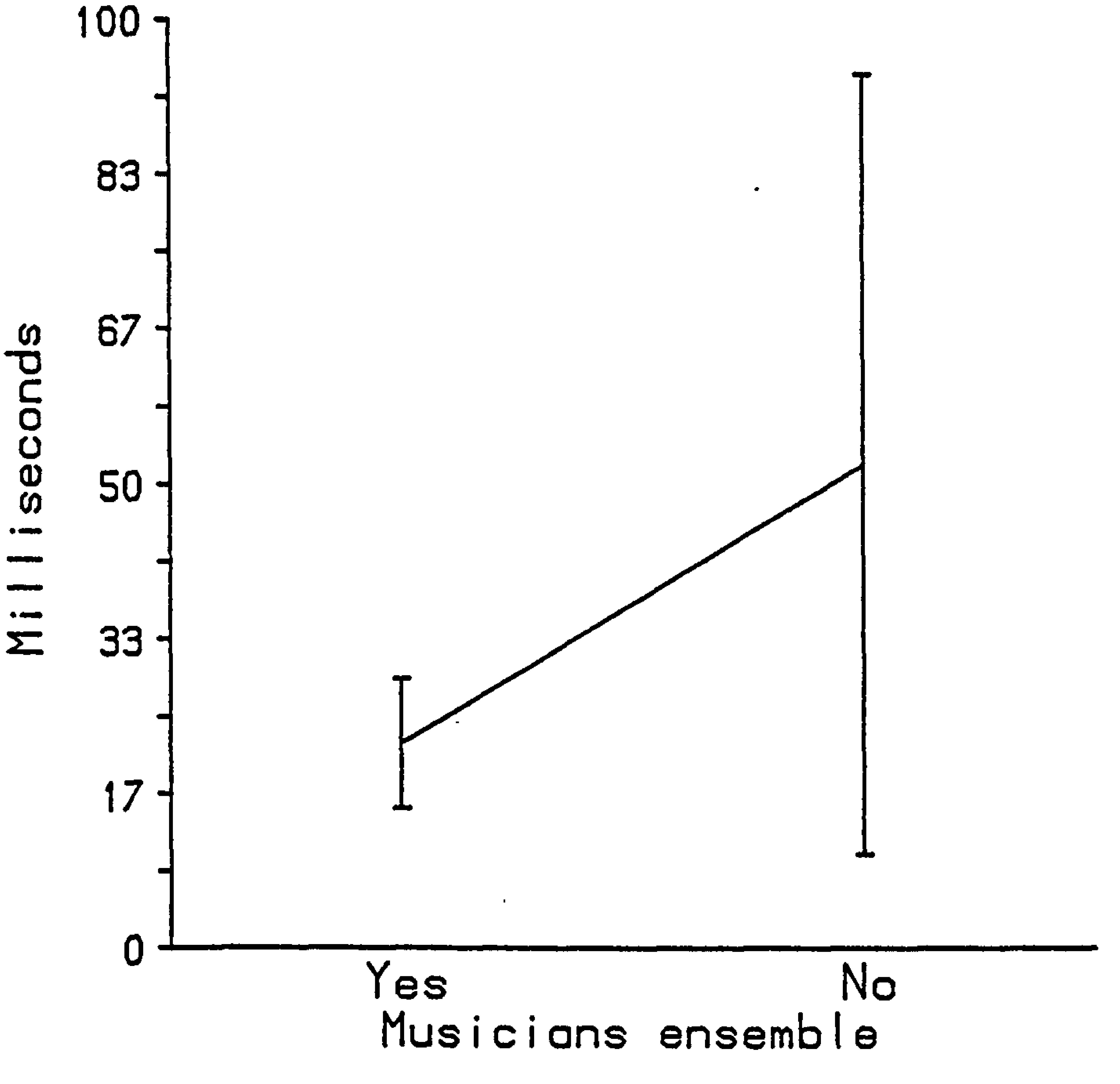


Figure 2.02
Range of differences between drummers
Ensemble and conducted

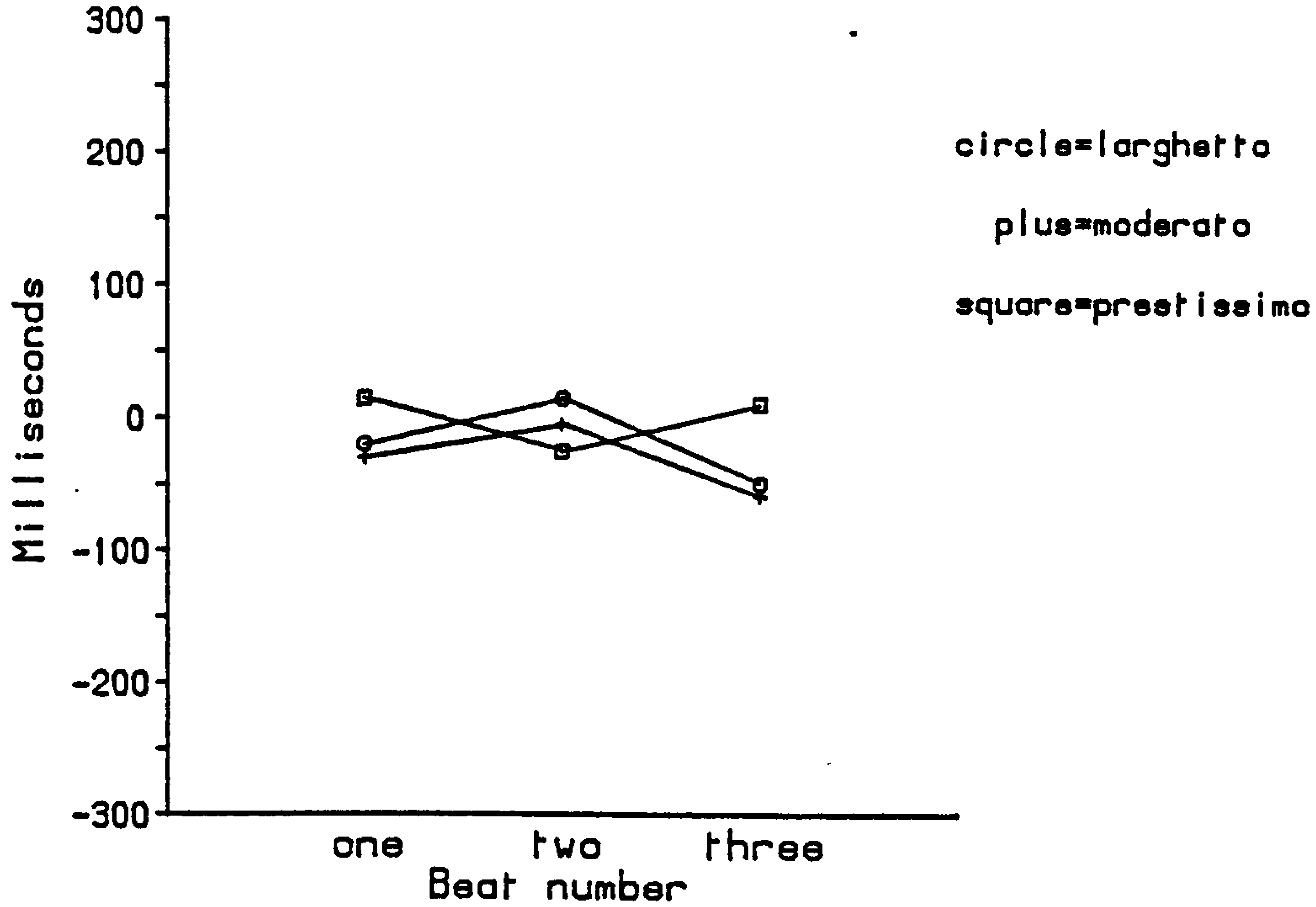


Figure 2.03
Range of differences between drummers
Ensemble but not conducted

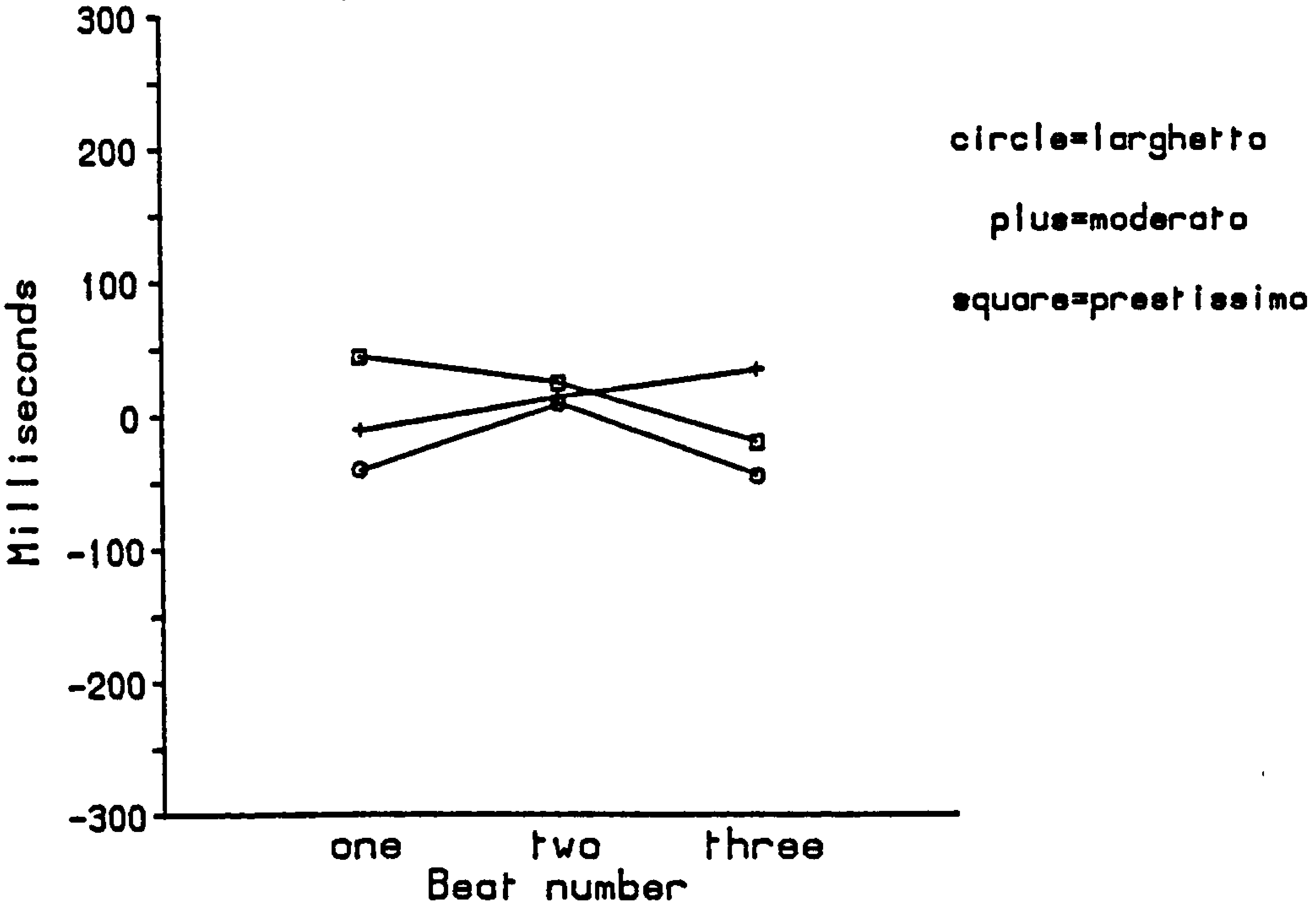


Figure 2.04
Range of differences between drummers
Conducted but not ensemble

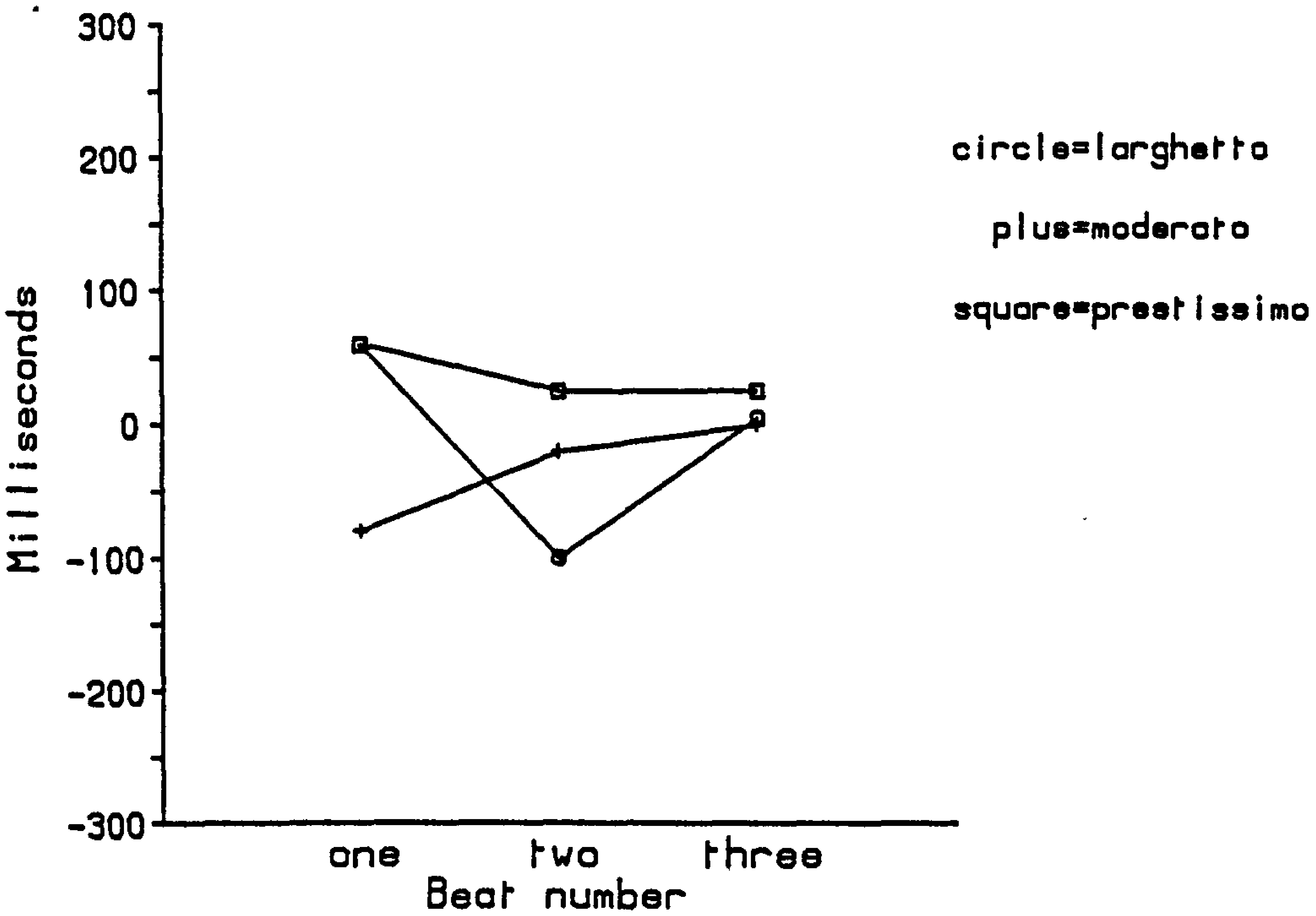


Figure 2.05
Range of differences between drummers
Neither conducted nor ensemble

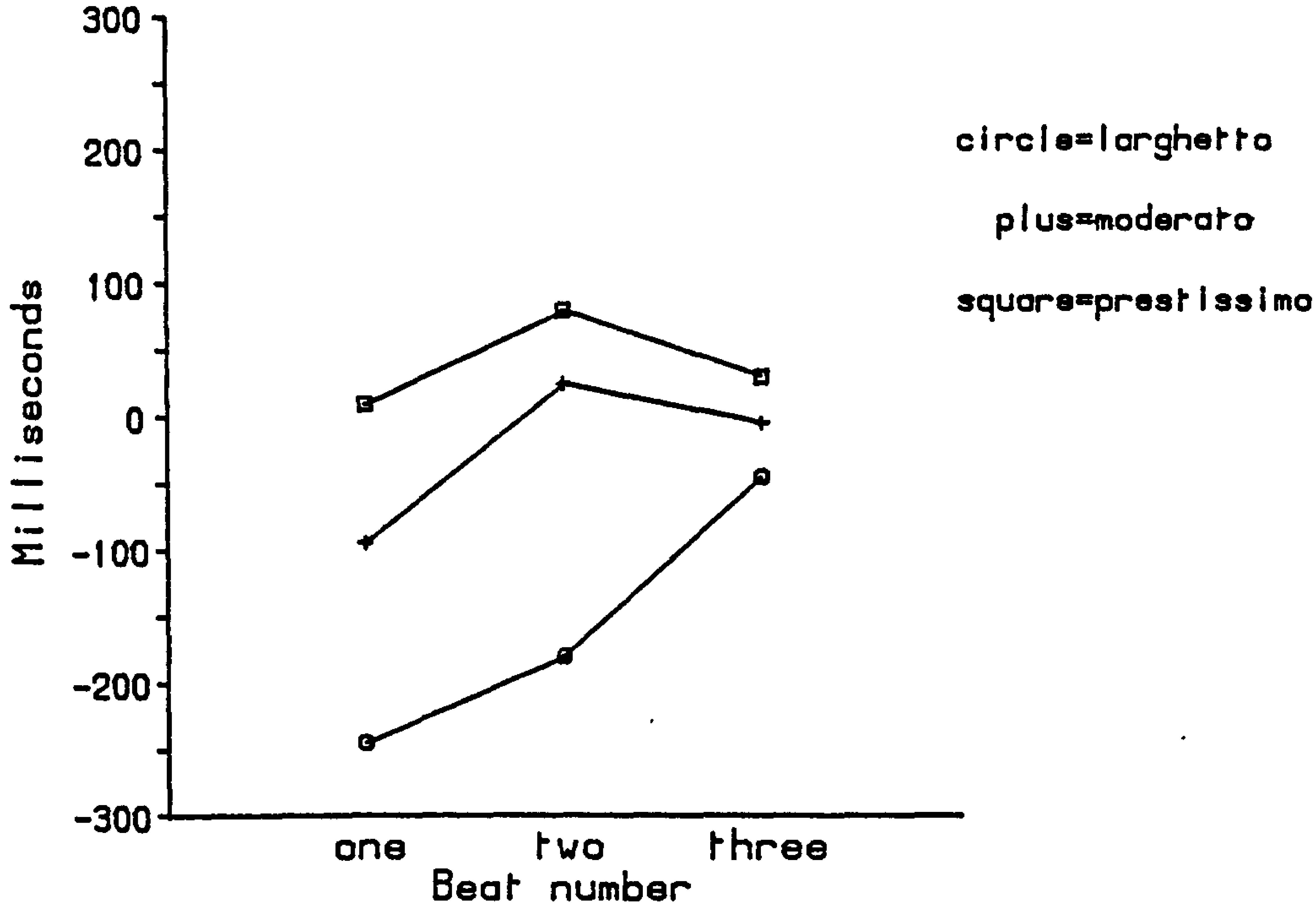


Figure 2.06
Average absolute differences
between drummers

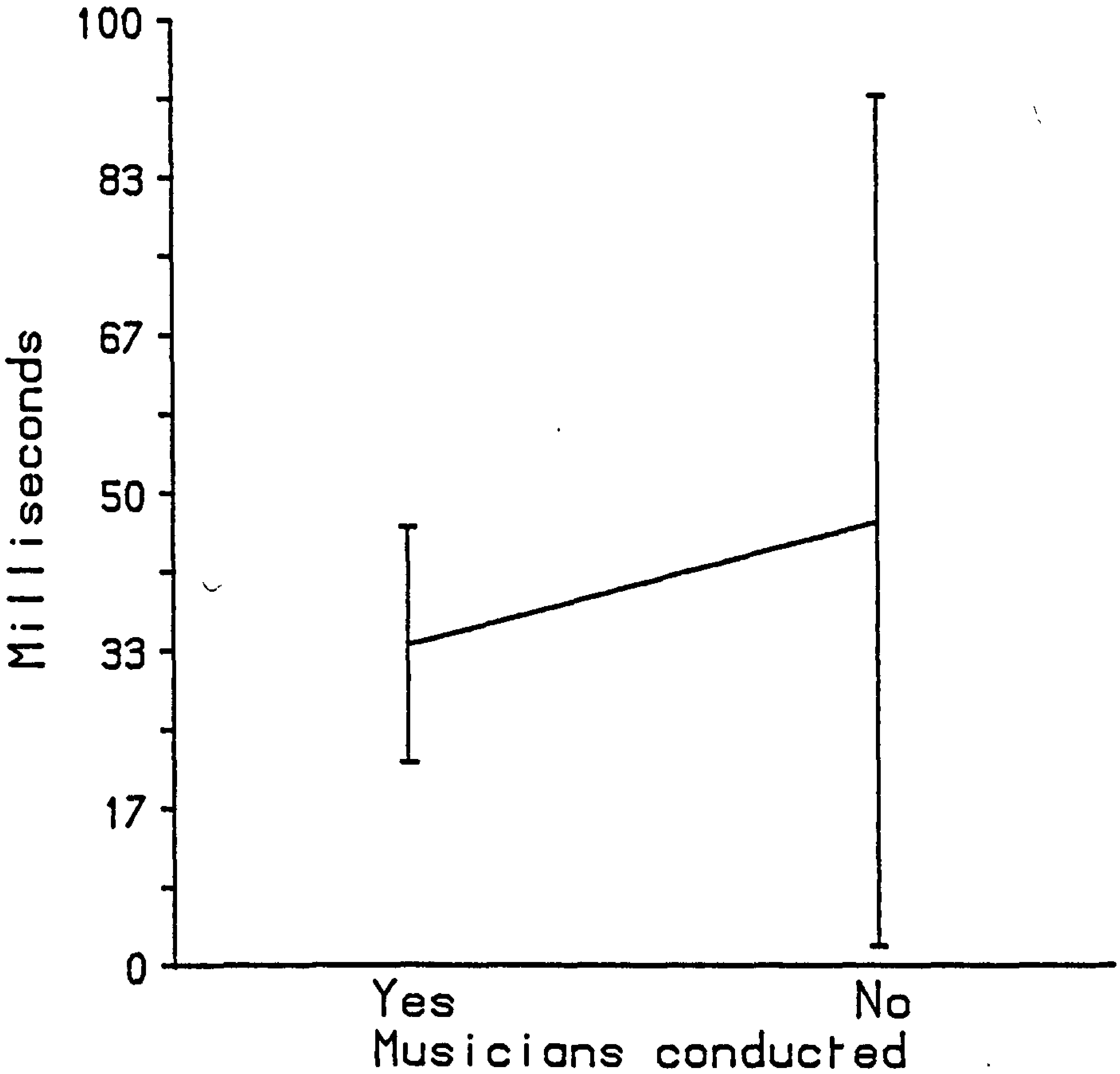


Figure 2.07
Differences between drummers
Ensemble and conducted

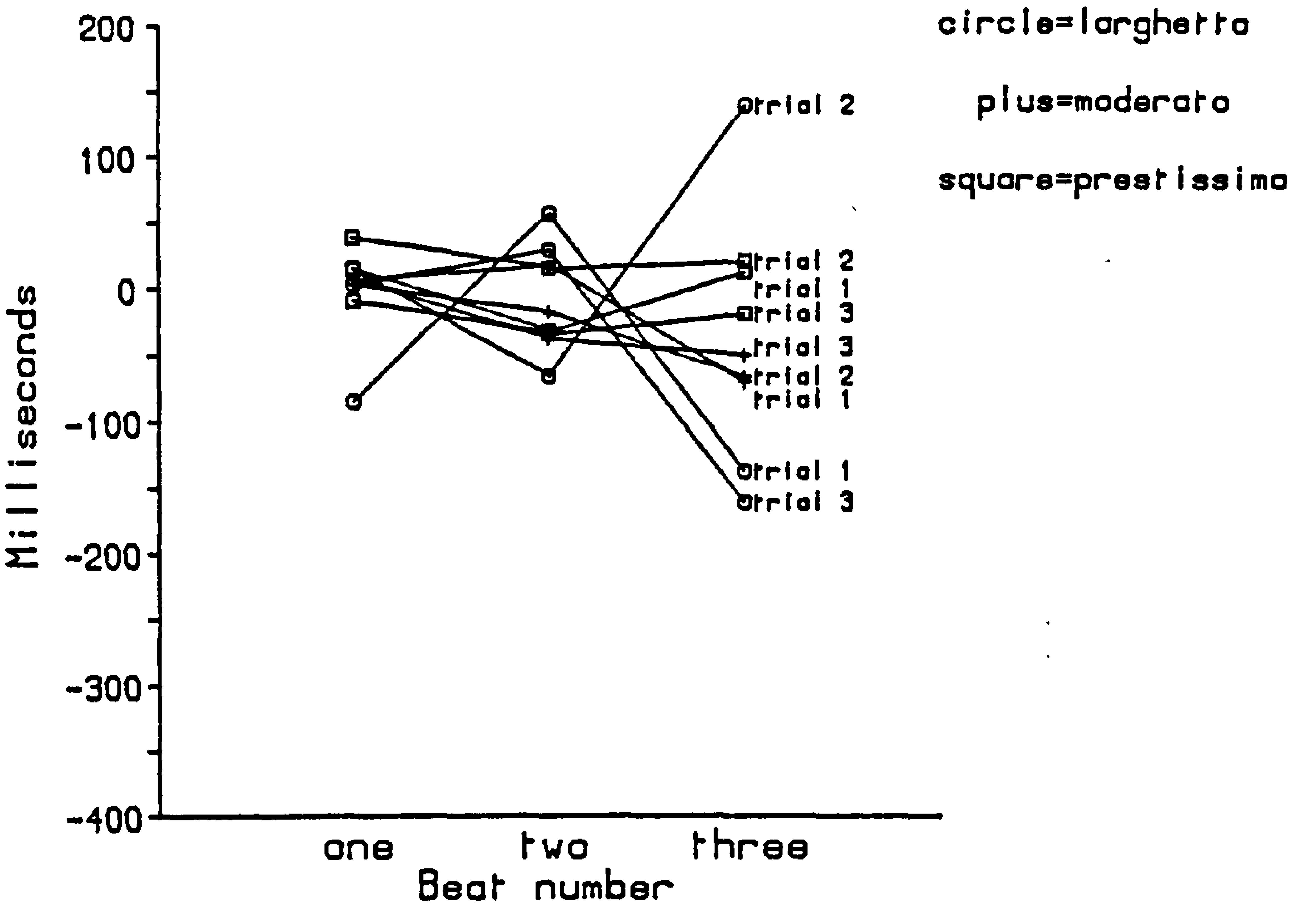


Figure 2.08
Differences between drummers
Ensemble but not conducted

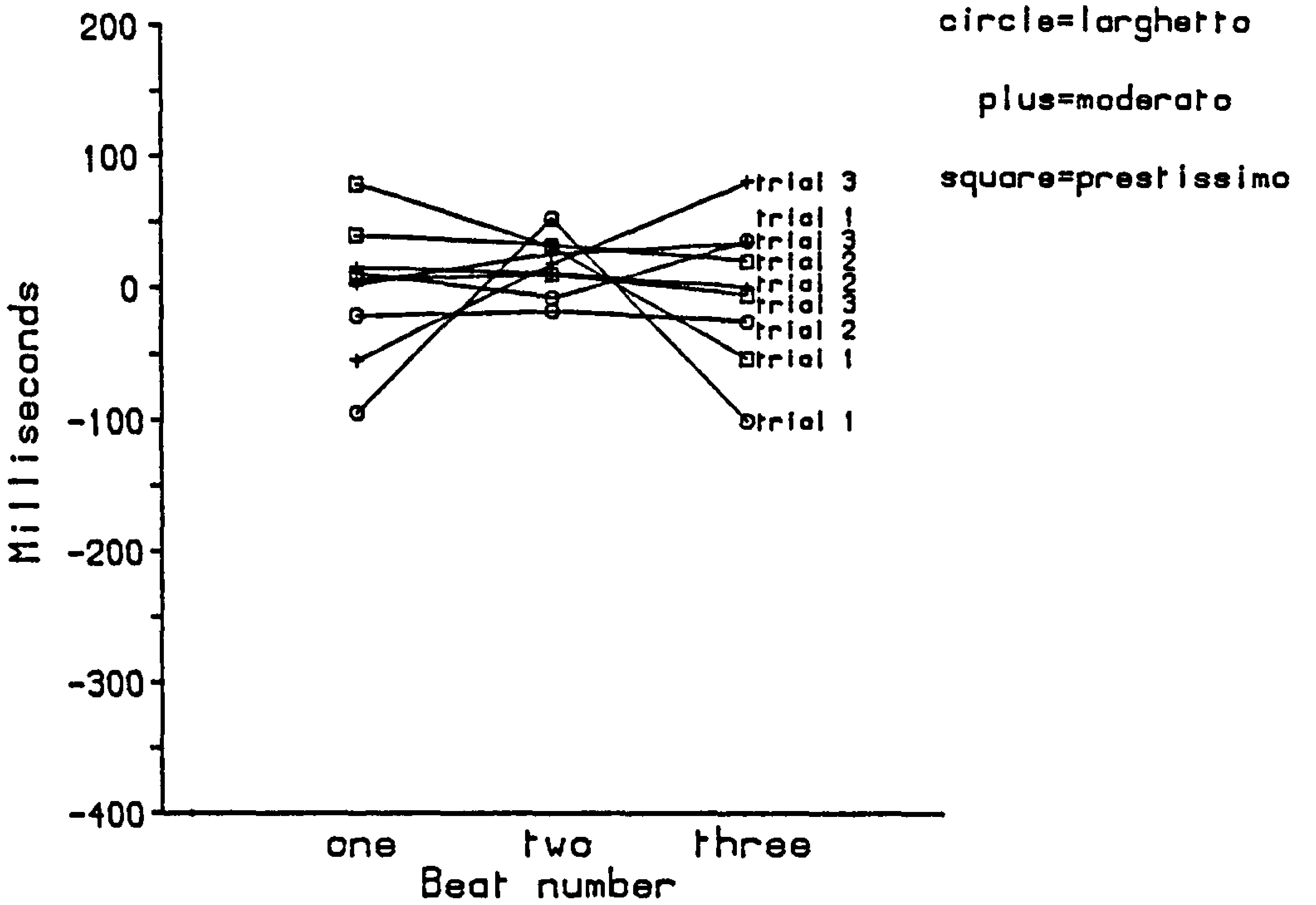


Figure 2.09
Differences between drummers
Conducted but not ensemble

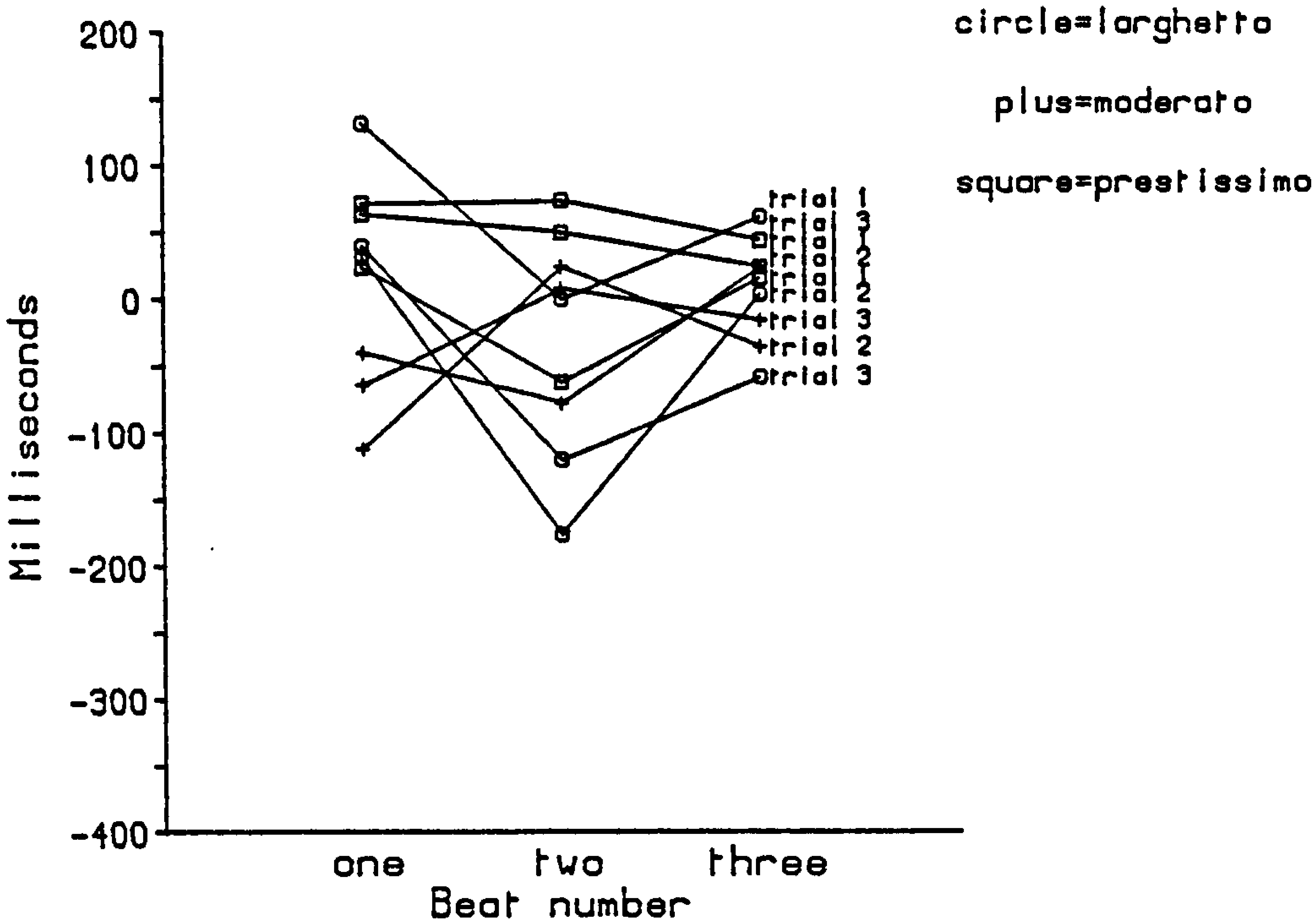


Figure 2.10
Differences between drummers
Neither conducted nor ensemble

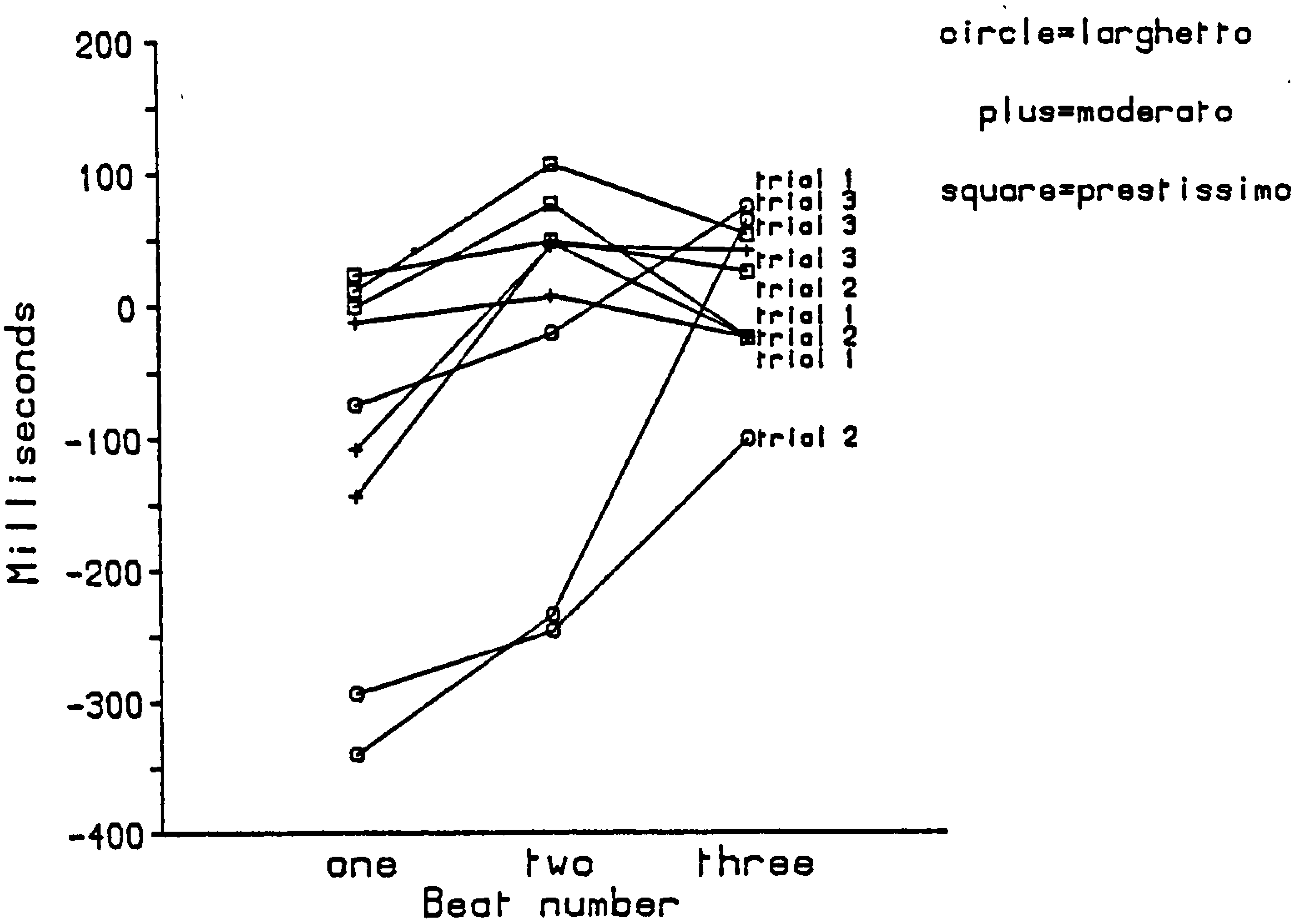


Figure 2.11
Average absolute differences
between drummers

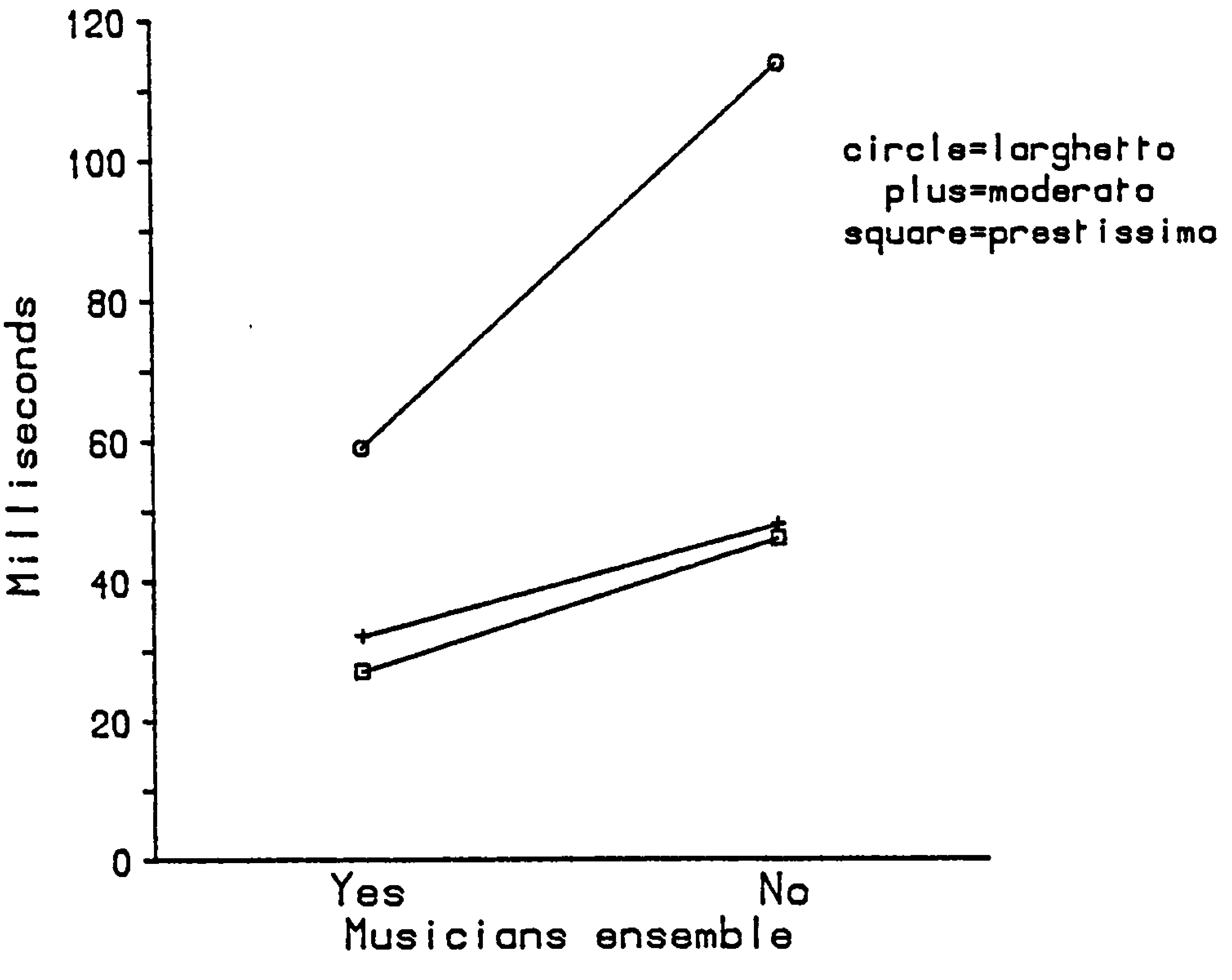


Figure 2.12
Average absolute differences between drummers

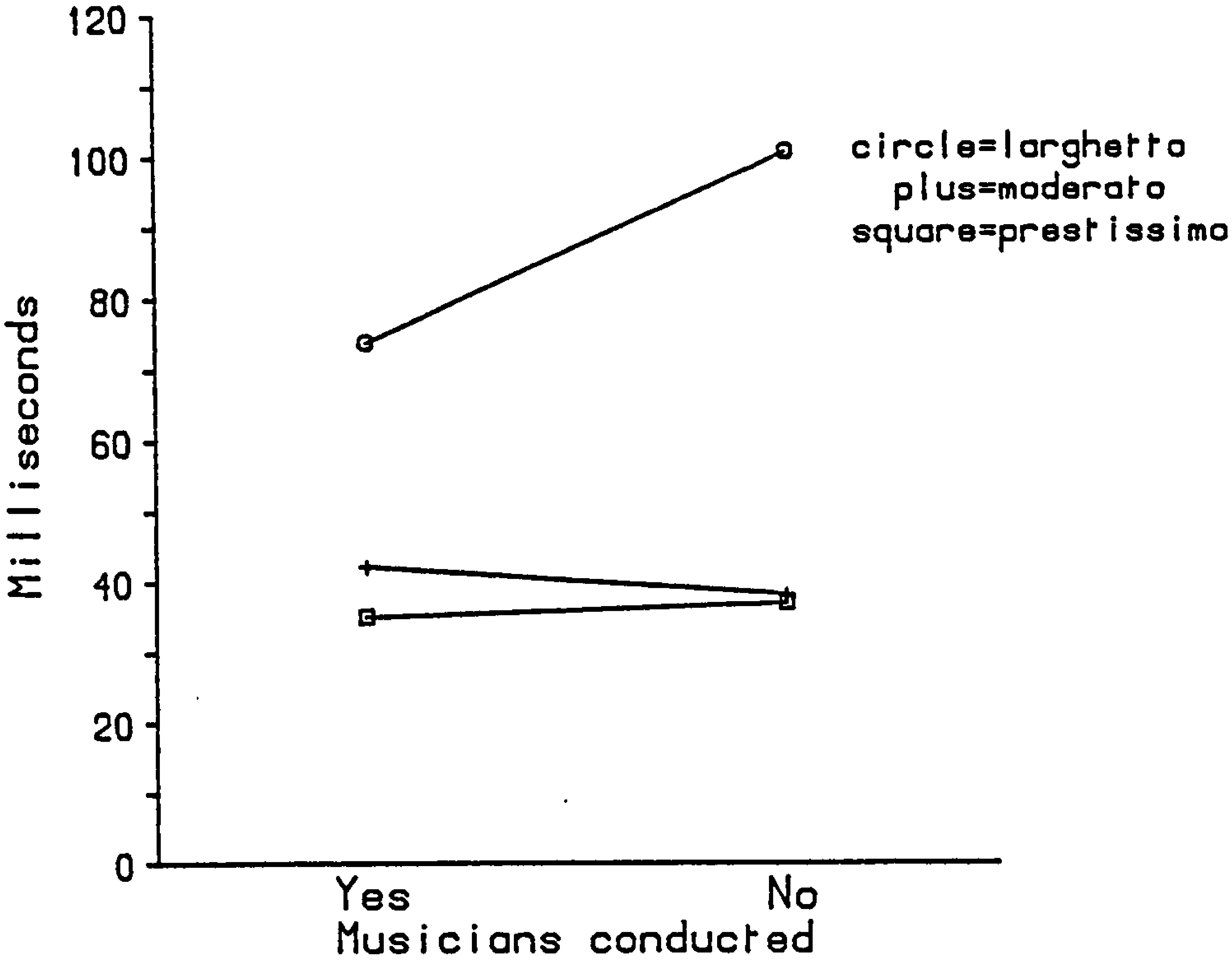


Table three

Difference ranges

The difference between the maximum and the minimum differences between the drummers across beat and replicate.

No-score series data

	Players ensemble		Players separated	
	cond	not cond	cond	not cond
Tempo				
1-Larghetto	332	108	288	416
2-Moderato	96	131	144	188
3-Prestissimo	84	133	136	132

(b) However, the effect of the conductor can only be considered in interaction. Remember that the conductor gives the first beat in every condition. Yet the difference between the drummers on that first beat approximately doubles when they are separated. This can be seen on comparing the discrepancy on the first beat in figure 2.7 with that in figure 2.9, and that in figure 2.8 with figure 2.10. Thus we should think of players as synchronising with each other on the first beat, rather than synchronising with the conductor. This answers the first question of the introduction. What then is the conductor's contribution?

The answer emerges when the difference between the conductor's beat and that of the first drummer is taken as the dependent variable. It is only possible, of course, to compare across trials where the conductor is present throughout. This is because where the conductor gives one beat only there is only one data point for comparison, which is insufficient.

This comparison, then, is between the condition where the players are together, and conducted, and the condition where the players are separated and conducted.

The result is very clear. When the players can see and hear each other they substantially ignore the conductor. When they are deprived of their ensemble, they focus on and remain close to the conductor's beat times. This means that they can focus on the conductor, but choose to do otherwise. The effect is illustrated in table four. Figure 2.13 also shows this effect, with a clear separation by tempo. Figure 2.14 shows the effect by ensemble, with the tempi again kept separate. It is necessary to show real, not absolute differences, as the difference between the conductor and the first drummer changes sign both over tempo and over ensemble. This is also why it is impossible to collapse across tempo.

Table four

Differences between the conductor and first drummer, by tempo

Where the values are negative, the drummer is anticipating the conductor.

Ensemble?		Larghetto	Moderato	Prestissi	Ranges, all tempi.
Yes	Mean	142.66	-111.33	-52.89	366.00
	SD	83.48	62.28	85.33	
No	Mean	20.89	-21.11	14.77	112.00
	SD	52.39	30.32	28.92	

Overall task difficulty

The results support an operational definition of "overall difficulty" as a compounding of the factors of ensemble and conductor, in that there is a linear relationship between the range of the differences between the drummers (over beat, replicate, and

Figure 2.13
Means and S.D.'s of differences between conductor and first drummer

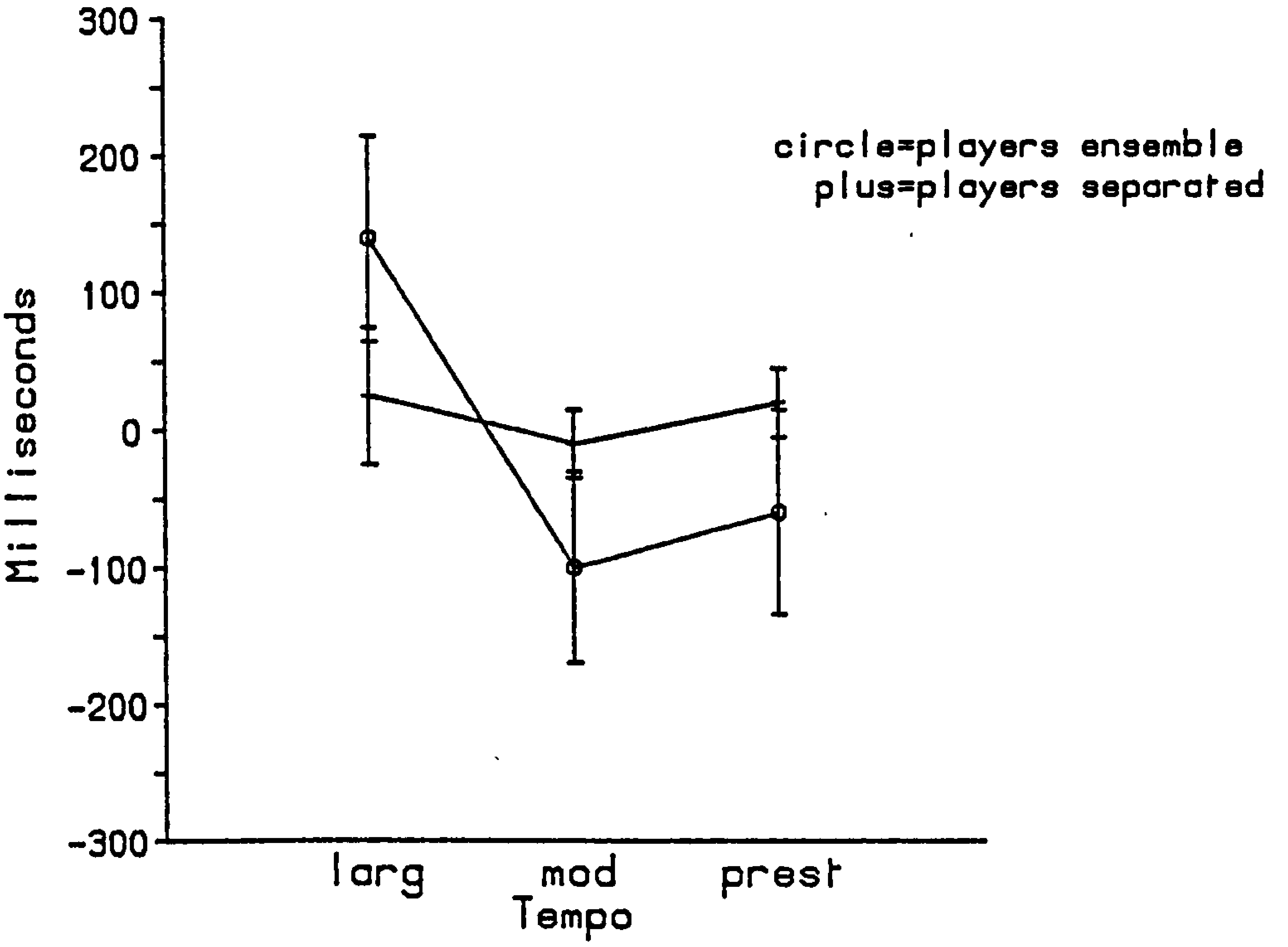


Figure 2.14
Means and S.D.'s of differences between conductor and first drummer

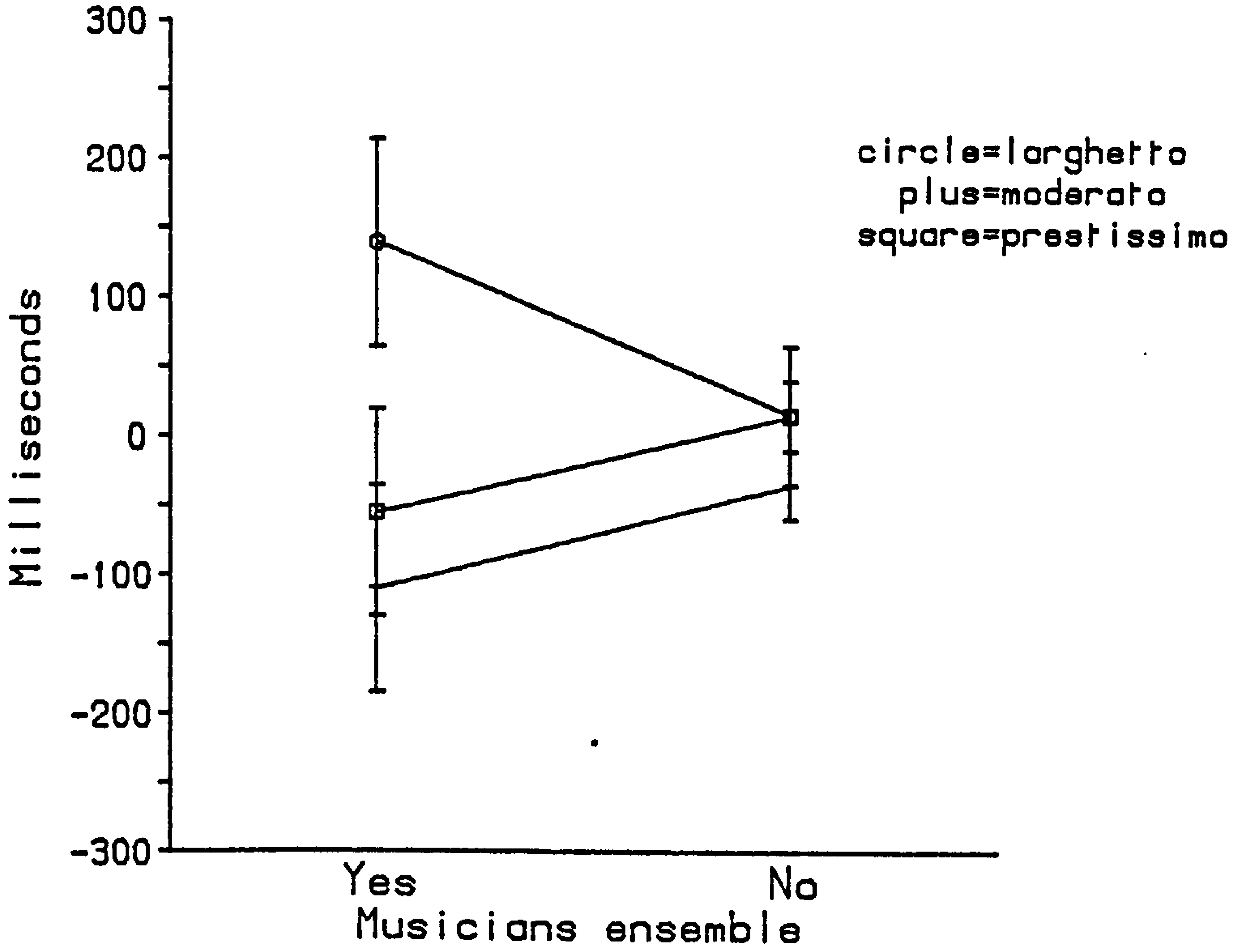
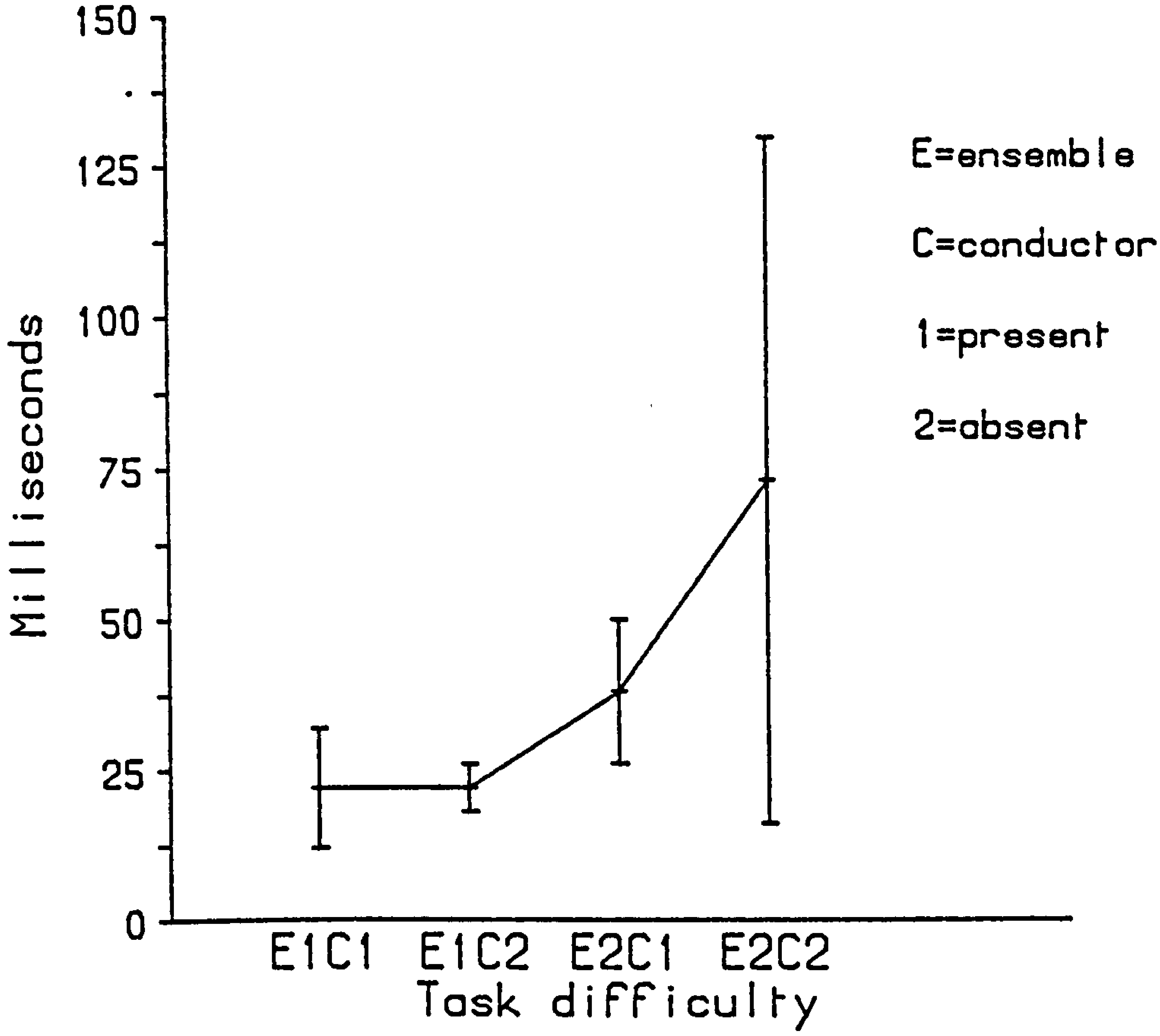


Figure 2.15
Average absolute differences between drummers



tempo) with this "difficulty" of the task. The relationship also obtains with the means of the absolute differences between the drummers, but is weaker. These means and S.D.'s are shown in figure 2.15. The relationship between the compounded variable and the ranges of the differences between the drummers is shown in figure 2.16. There is an exception; the relationship does not obtain at larghetto, the hardest tempo, so linearity is only obtained when this level is excluded. The ranking is as shown in table five.

<u>Table five</u>

Conditions	Ranges
(1) Ensemble and conducted	108
(2) No conductor, but ensemble	136
(3) Conducted, but no ensemble	184
(4) Neither ensemble nor conducted	246

The increase in the overall range of the differences over beat, replicate and the two tempi, moderato and prestissimo, can be seen in figures 2.7 to 2.10, but is lost in the summary figures 2.2 to 2.5, which are collapsed across replicate. This ranking is also obtained with the Bartok series. The ensemble and conducted condition is the normal and optimal situation. The separated and not conducted condition is the most deprived and therefore hardest. This answers the fourth question of the introduction. The players clearly cannot compensate for the loss of feedback. Of particular interest is the ordering of the loss of conductor and loss of ensemble. This is the first significant divide, as the first two grades in the ranking are relatively close. This means that to be separated from the other player is a more serious loss in terms of accuracy than the loss of the conductor. This confirms the answer to the first question of the introduction. There is a 73.9% increment in range between grades two and three. Therefore it could be said that to lose track of the other players is 73.9% worse than losing track of the conductor. The increase between the third grade and the fourth is also of the 75% order (74.8%), showing the effect of the loss of all feedback.

The average range of inter-player beat discrepancies, taking real values and excluding the most deprived condition, was 161.3ms, with an SD of 87.3ms. The values within conditions are given in table five and shown in figure 2.16.

Minor effects

Tempo

When the differences between the drummers' beats are analysed as real values there is an effect of replicate. On conversion to absolute differences this effect disappears, leaving the interaction of tempo * ensemble * conducted as the effective factor. More precisely, we have an ensemble * conducted interaction which varies systematically by tempo. The effect of tempo, while significant overall, only becomes apparent when the players are separated. In effect, the replicates at each tempo fall into bands, but the bands do not start to separate out until the players are separated. This can be seen if figures 2.7 and 2.8 are compared with figures 2.9 and 2.10. The effect of tempo is on the range of the differences. This is shown in figure 2.17. The slower the tempo, the larger the variation in beat placings. It is a diminishing relationship, as the main distinction is between larghetto (with a large range) and the others, moderato and prestissimo (with similar, smaller ranges). The clearest separation of the tempi is where the players are separated and not conducted. When the conductor and/or the other player is present, the tempi profile is less clear as the separation is overlaid by the adjustment effect (see below). There is a further general effect of tempo which is for the second drummer to be progressively later with respect to the first drummer as the tempo slows. This is a weaker effect, as it does not show in all conditions. There is an idiosyncratic effect too; the second drummer tends to start in front at moderato and, to a lesser extent, at larghetto. This effect does not appear at prestissimo. The effect is weak, and only appears when the players are separated. These two secondary effects both show that the players phase-shift at different tempi with respect to each other. This indicates that the relationship between the players is dynamic rather than static, because the primary effect means that it is unlikely that only one player is being affected by the changes in tempo.

Table six gives the means and S.D.'s of the absolute discrepancies between the players, summed across the minor factors of beat and replicate, within the major factors of ensemble, conductor, and tempo. Table seven summarises which of the interactions of these three main factors are statistically significant.

Figure 2.16
Range of differences
between drummers

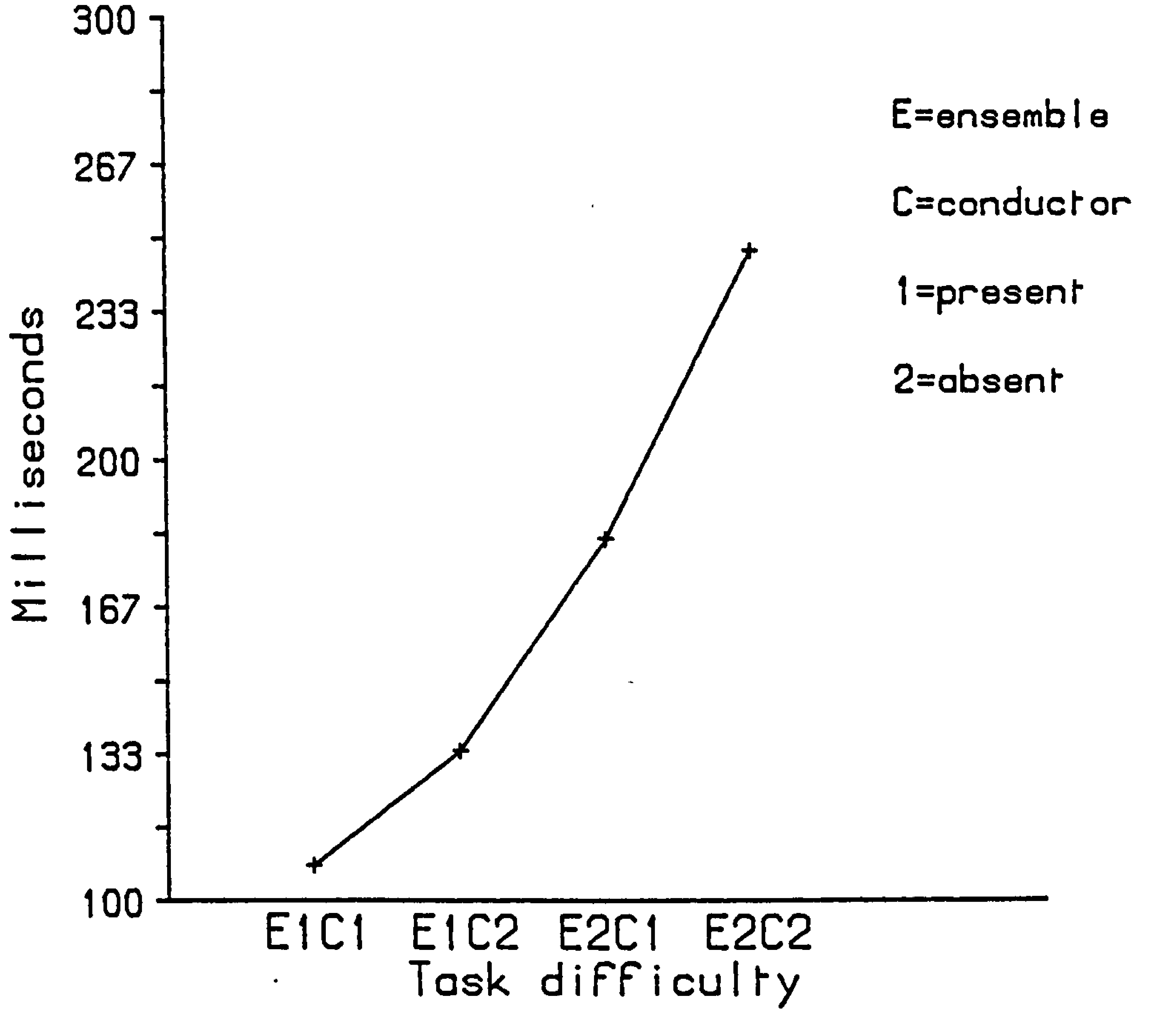


Figure 2.17
Range of differences
between drummers

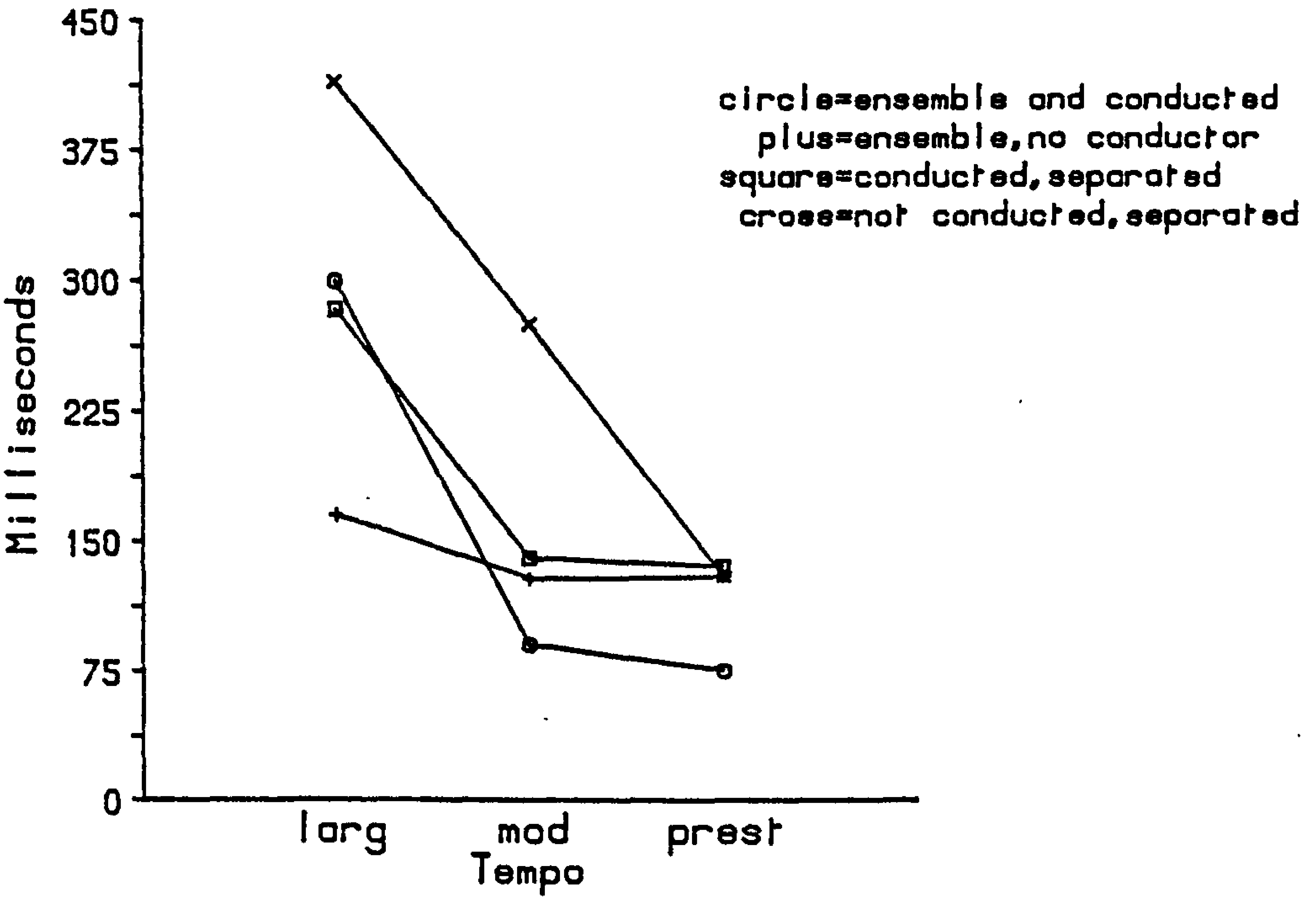


Table six

Means and S.D.'s of discrepancies

Factors present		Larghetto	Moderato	Prestissimo
Both	Mean=	78.2	37.6	22.9
	S.D.=	56.4	18.0	10.9
Ensemble	Mean=	40.4	25.6	30.7
	S.D.=	33.9	25.8	24.7
Conductor	Mean=	68.0	45.3	47.6
	S.D.=	57.4	35.2	21.5
Neither	Mean=	160.9	50.7	44.9
	S.D.=	118.8	46.1	33.8

N=9 in each case. Note that the discrepancies, where information is available to the players, are generally in accord with the figures obtained by Rasch (1979), who found that the S.D. of asynchrony ranged from 23 to 40ms with wind trios and 35 to 50ms with string trios.

Table seven

Tests of significance

No-score series data, differences between drummers in absolute values

(1) first analysis - three-way interactions
(includes two-way & single factors)

Interaction	F-Ratio	Significance level
(1) Ensemble*Cond*Beat	1.74	-
(2) Ensemble*Tempo*Beat	1.93	-
(3) Cond*Beat*Tempo	3.74	$P < 0.1$ without (1)&(2)
(4) Ensemble*Cond*Tempo	5.68	$0.05 < P < 0.1$ $P > 0.1$ (3.75) when(1) &(2) removed. $P < 0.1$ when (3) removed.

(2) Second analysis - two-way interactions
(includes single factors)

(1) Beat*Tempo	0.18	-
(2) Ensemble*Beat	2.54	-
(3) Cond*Beat	5.96	$P > 0.01$ ($P > 0.05$, 5.3) when (1)&(2) removed.

(3) Third analysis - single factors

(1) Tempo	$0.1 > P > 0.05$
(2) Ensemble	$0.1 > P > 0.05$

Compensating & adjusting effect (1) Within trials

A player may make a correction to a subsequent beat placement if an earlier beat is incorrectly placed. This would give rise to a change from a positive to a negative slope (or vice-versa) around the second beat in the plot of the first drum - second drum differences. This is the case in all but seven of the thirty-six observations (the null hypothesis that the slope of one stage does not determine the next can be rejected with $P < 0.03$). This can be seen in figures 2.7 to 2.10.

Four types of correction were observed. These were as follows.

(1) There are discrepancies on beats one and three, none on beat

two. The players correct the error of beat one on beat two, while on beat three they exhibit a separate error.

(2) Beat three is nearer a zero discrepancy than either beat one or two. The players make an initial correction between beats one and two, then a further correction between two and three.

(3) Beat two is on the other side of the zero axis from beats one and three. The players overcorrect from beat one, then attempt to correct the overshoot.

(4) Beat two is nearer zero than either one or three, but not at zero, unlike type 1 corrections. A variant of this is that beat one is not zero, beat two is an increased error in the same direction. The question that both raise is, why are the remaining or initial discrepancies not corrected in the right direction? The most likely answer is that there must be a limin for detection of discrepancies. Thus subliminal discrepancies are treated as zero discrepancies, which subsumes type 4 corrections in the class of type 1 corrections. The value of the limin calculated from the instances of type 4 corrections is in accord with Michon's (1967) figure of 25ms, with a mean of 18.0ms and a S.D. of 10.2. The instances are given in table eight.

Table eight

Replicates (R) on which type 4 corrections occur, actual discrepancies in brackets.

Factors present	Prestissi	Moderato	Larghetto	N	Mean	S.D.
Both	R2(18)	R2(8),R3(24)	R3(8)	4	14.5	7.9
Ensemble	R3(8)	R1(24)	R2(14)	3	15.3	8.1
Conductor		R1(40)		1	40.0	0.0
Neither	R2(24),R3(12)			2	18.0	8.5
Over all conditions				10	18.0	10.2

There are a small number of trials with no apparent corrections, that is, where there is no change in the sign of the slope (see figures 2.7 to 2.10). Two (one at moderato in the ensemble but not conducted condition, and one at prestissimo in the separated and conducted condition) are only slight continuations of an existing slope. Only five replicates exhibit pronounced and unaltered slopes. Three of these occur at one tempo in one condition, at larghetto when the players are separated and not conducted. All are positive slopes. The two remaining are at moderato in the ensemble but not conducted condition (which is positive) and at prestissimo in the ensemble but not conducted condition (which is negative). So of these five exceptions, three are where there is no contact between the players (either directly or via the conductor) and therefore there is no feedback available to make a correction. The other two exceptions both have a transition across the zero line, and there are two possible explanations. The first is that there are two consecutive errors with a single correction interposed. If we momentarily adopt the first drum times as the standard, then this means that the second drummer is late, then corrects, then makes a second mistake on the early side at prestissimo in the ensemble but not conducted condition, or vice-versa at moderato in the same condition. The second possible explanation is that as he is still 28ms late on the second beat in the prestissimo case he may have made a further adjustment in the early direction and "crossed over" the other player's beat. This explanation cannot apply in moderato case, which suggests that the first explanation is correct.

The significant conductor * beat interaction reflects the internal correction that makes beat an important variable. Note that the possibility of correction depends on the presence of the conductor. The conductor * beat interaction is independent of ensemble.

Generally, large corrections are obtained when either the conductor or the other player is visible, but not both. Compare figures 2.7 with 2.8 and 2.9. In the optimal condition, when the players are conducted and together, there are still corrections, but there is a relatively tight grouping of results and the corrections are small. In the most deprived condition, when the players are deprived of the conductor and their ensemble, there are no corrections at all at larghetto, there is a simple drift. See figure 2.10. The drift, probably coincidentally, is back together. This means that the players arrive at different interpretations of both the starting time and the tempo information available from the conductor's initial beat. This answers the second question of the introduction. For the drift to be towards a smaller inter-drummer difference on the third beat, one musician must be early and slow, or the other late and fast.

The finding that within-trial correction occurs in almost every trial means that the players must be engaging in a continuous tracking and correction process. The beat must be the level of immediate control, as corrections are to successive beats. As we shall see, the correction effect does not emerge in the Bartok series. In the Bartok series, there was a formal assignation of roles, one player to the first part, the other to the second. The second player's task was to synchronise with the first. In the no-score series, although this ordering was preserved in the analysis, there was no such assignation. This would account for this within-trial correction, as it is in effect a hunting process, with both players tracking rather than one maintaining a strategy and the other attempting to match.

Compensating & adjusting effect (2) Over replicates

There are two important points about the effect of replicate. The first concerns larghetto, the second concerns moderato and prestissimo. At the slow tempo, the second replicate shows an opposite adjustment to the first and third replicates, though only when the players are ensemble. See figures 2.7 and 2.8. This could be a cognitive effect: the first trial shows one pattern, in the second attempt the players compensate for the overall pattern error of the first, in their third attempt they compensate for the overall pattern error of the second trial. For example, if either player is late-on time-late in one replicate, and adjusts for the incorrect beats, you could then see an early-on time-early. This is the kind of reversal observed. This appears to be a very similar hunting process, over replicate rather than beat.

The reason why the effect of replicate disappears when the absolute values of the drummers' differences are taken is partly that this compensatory effect over replicate is removed. Absolute values 'remove' the direction of error, thus we lose the identity of the drummer. The effect is shown in figures 2.18 to 2.21, which show the absolute differences between the drummers.

The other point is that there is, most noticeably at moderato and prestissimo, a practice effect over replicates one to two to three. The ranges of the the drummer's differences get progressively smaller. This only obtains when the players have some contact with each other, either directly or via the conductor.

Beat

It is necessary to collapse across tempo to see a pattern emerge for beat (see figure 2.22). This pattern is largely due to the contribution of one tempo, larghetto, where there is the clearest separation between conditions. At the other two tempi, the variances of the conditions largely overlap. This is shown in figures 2.23 to 2.25. In figure 2.22, there is an apparent progressive increase in the total variance over beats one to two to

Figure 2.18
Absolute differences between drummers
Ensemble and conducted

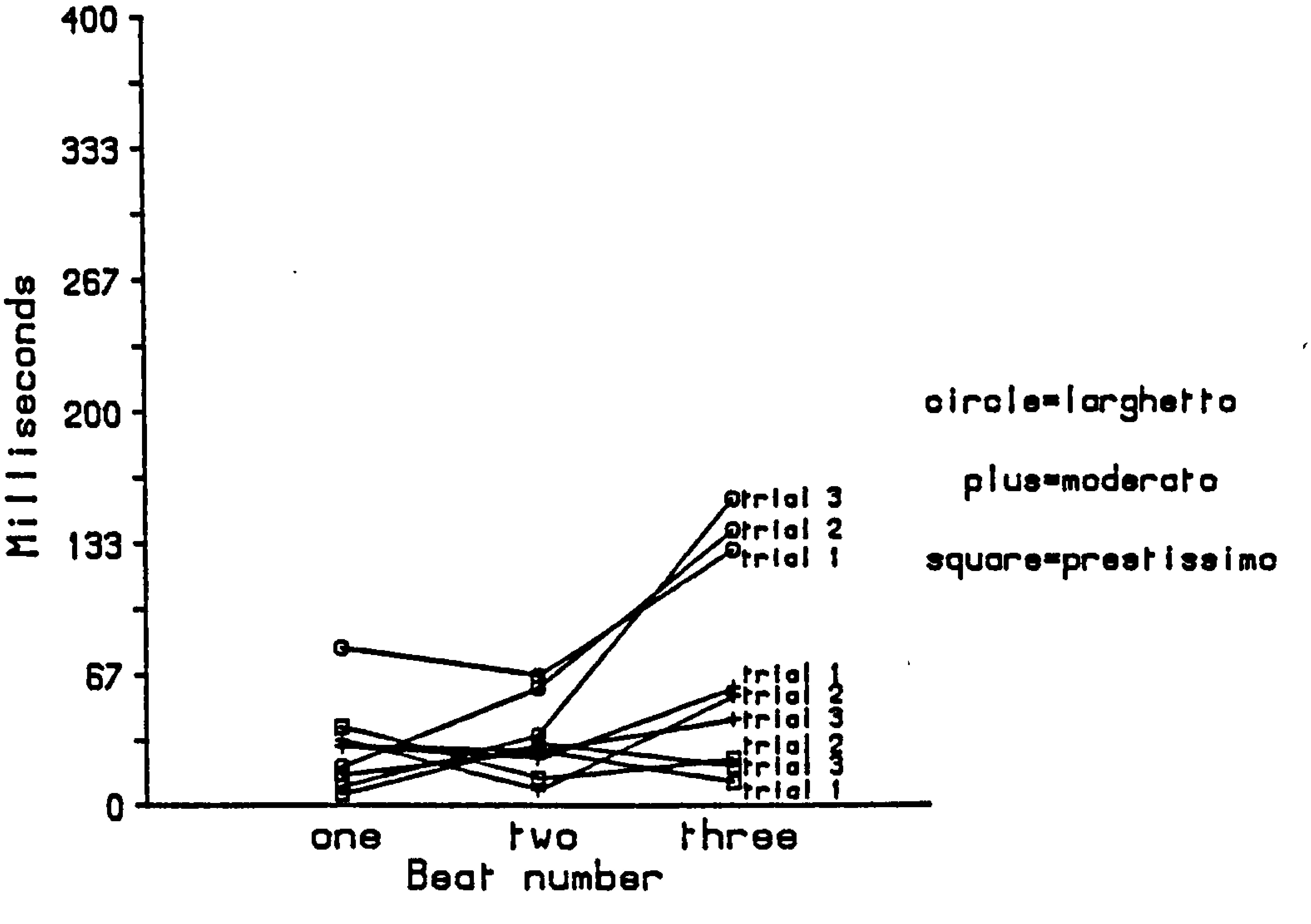


Figure 2.19
Absolute differences between drummers
Ensemble but not conducted

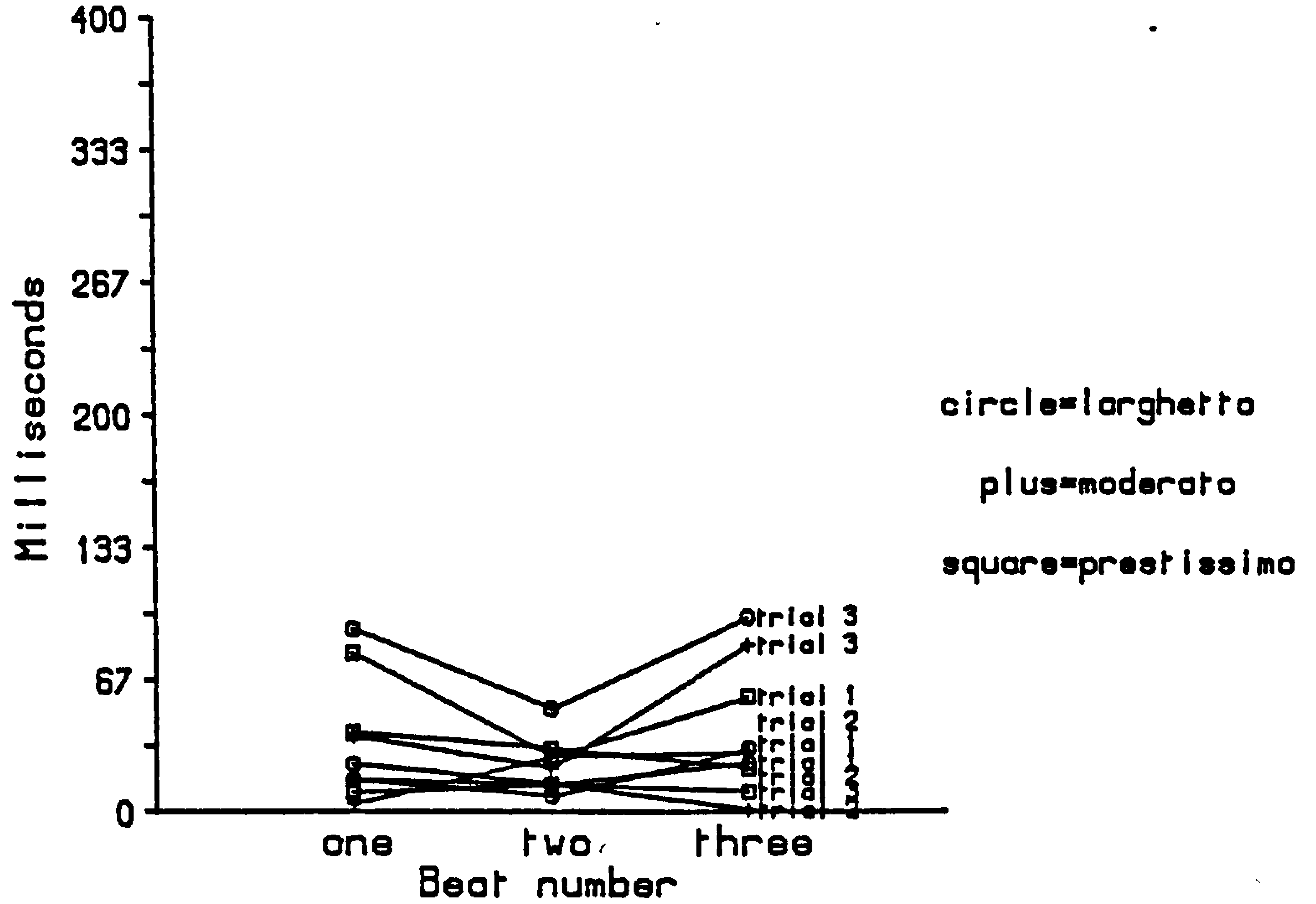


Figure 2.20
Absolute differences between drummers
Conducted but not ensemble

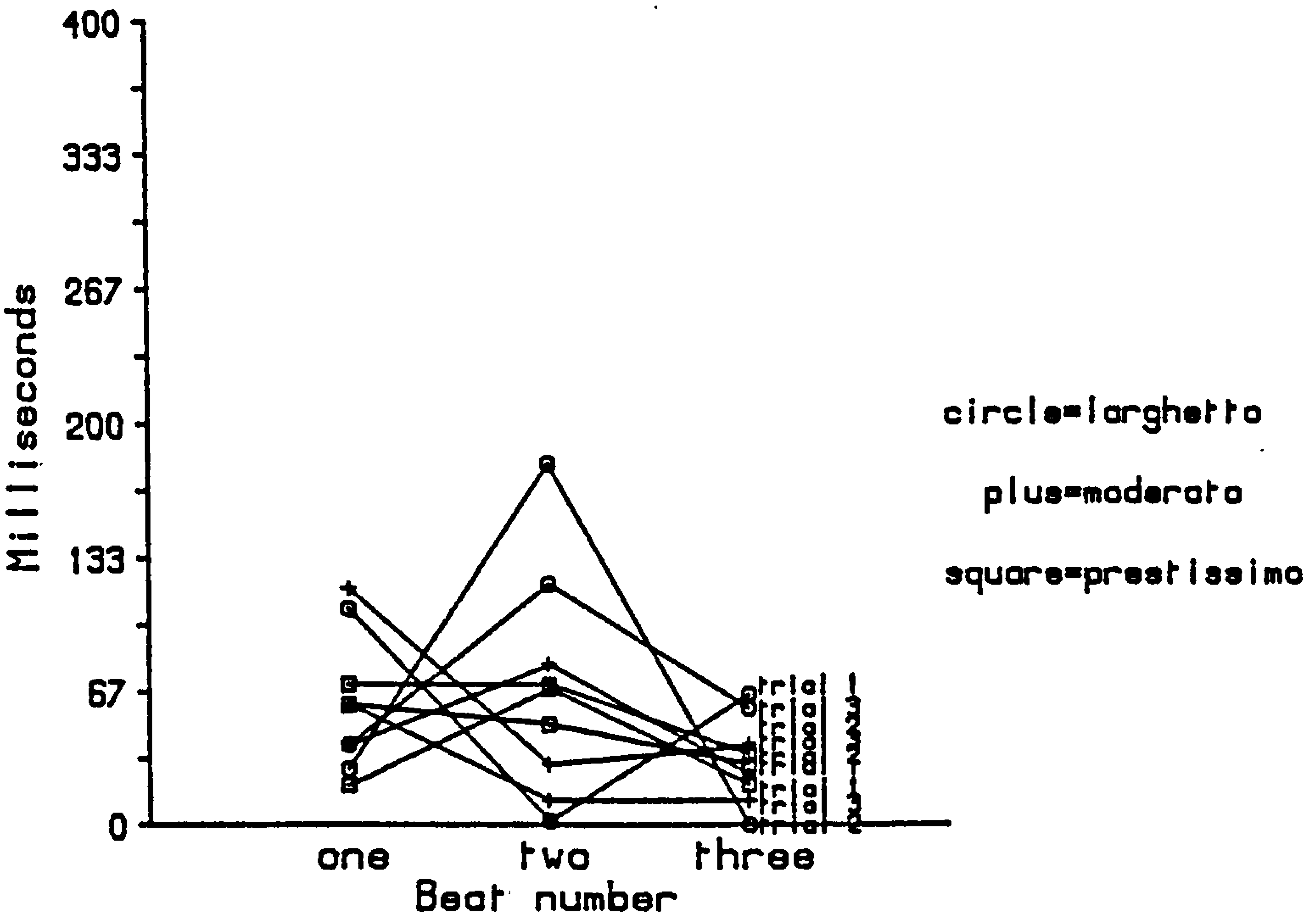


Figure 2.21
Absolute differences between drummers
Neither conducted nor ensemble

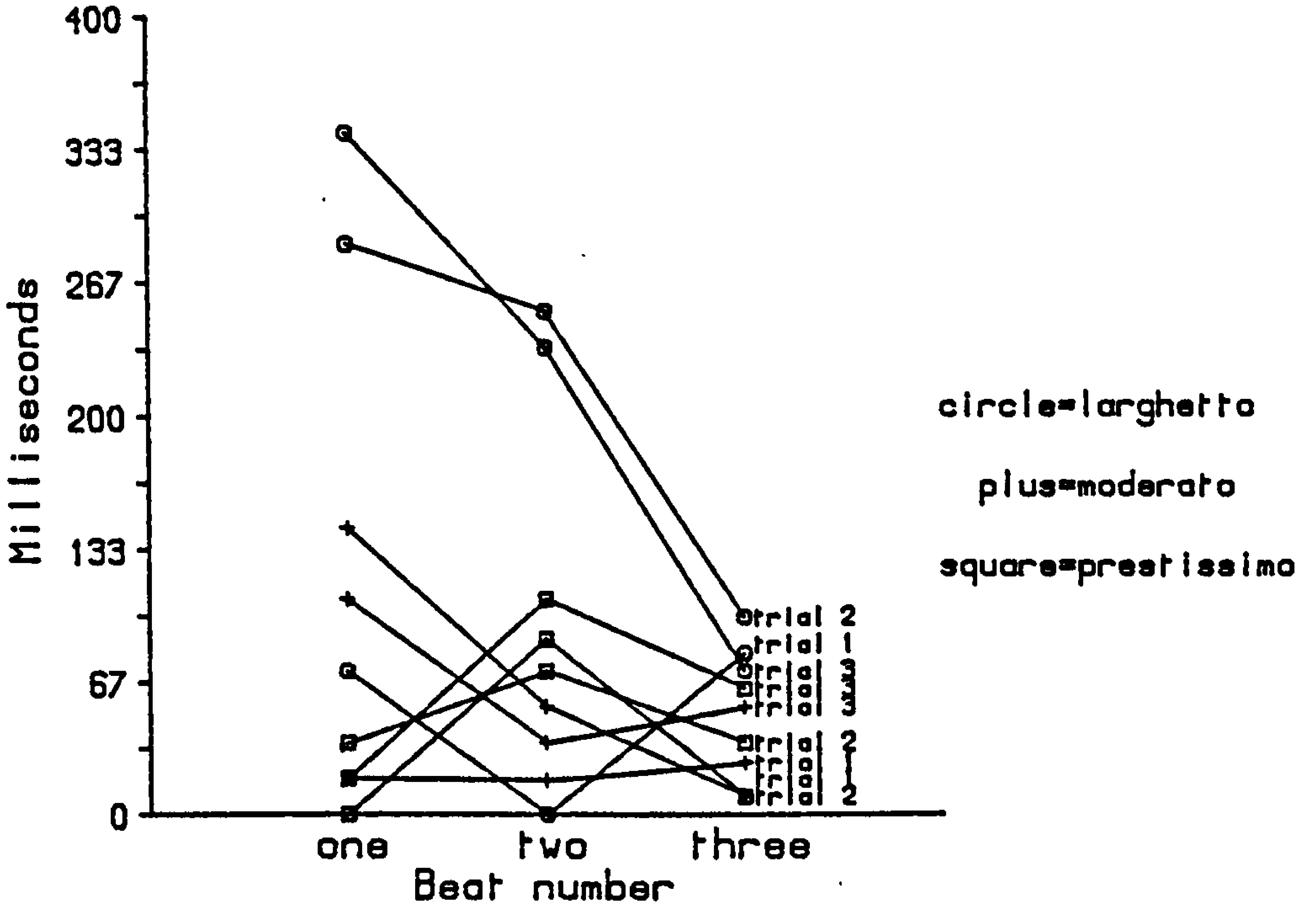


Figure 2.22
Average ranges of differences
between drummers

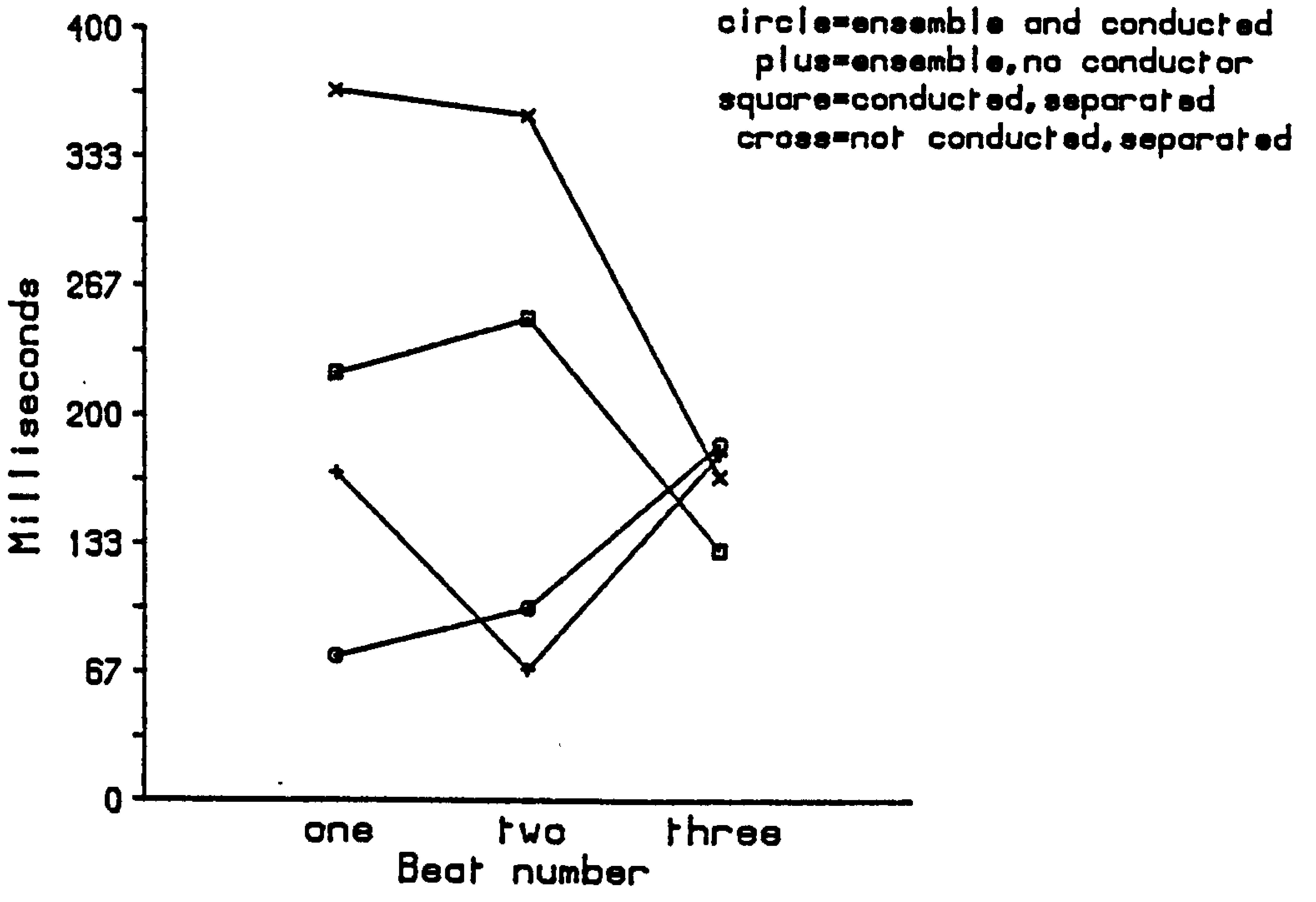


Figure 2.23
Ranges of differences
between drummers
At larghetto

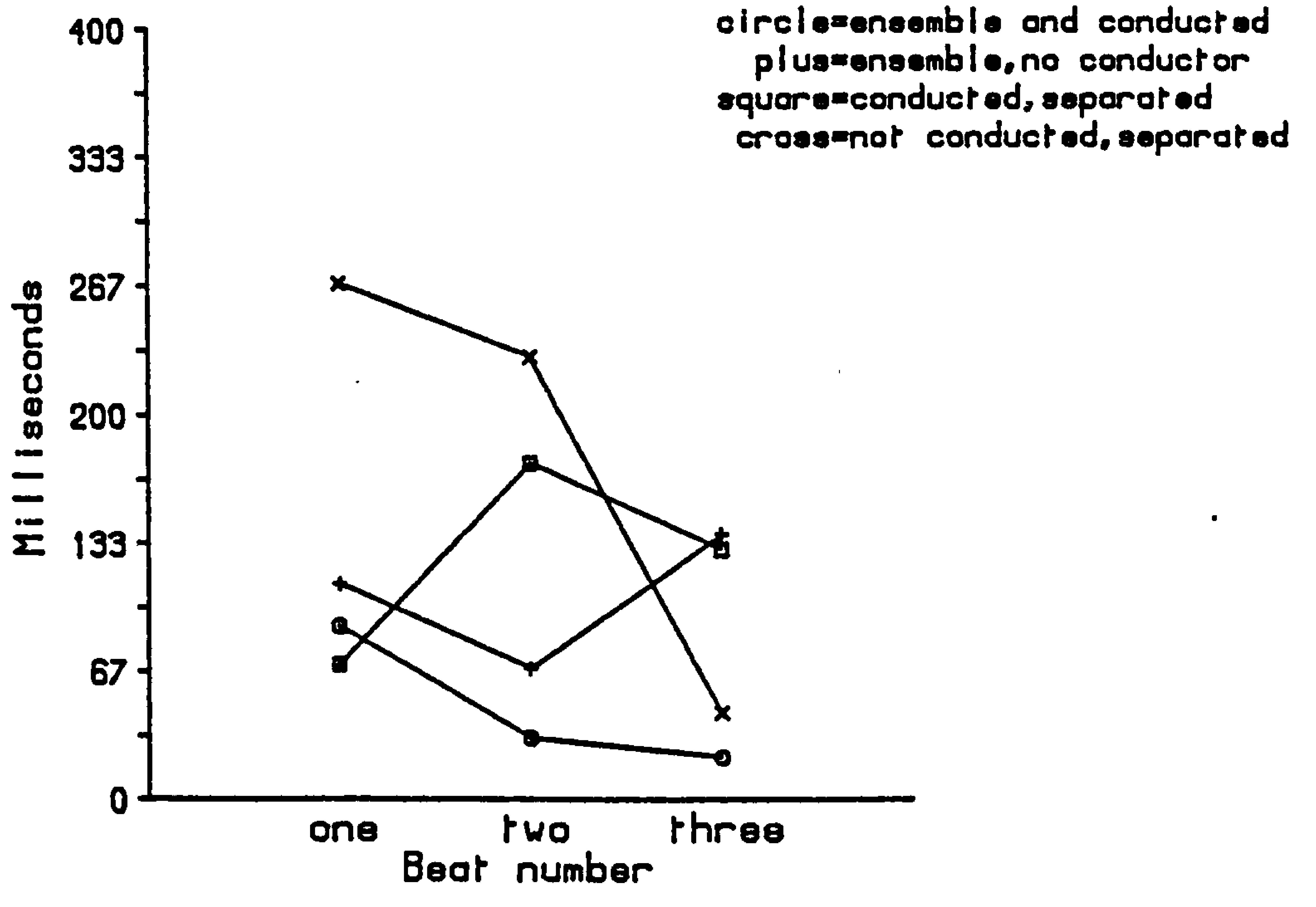


Figure 2.24
Ranges of differences
between drummers
At moderato

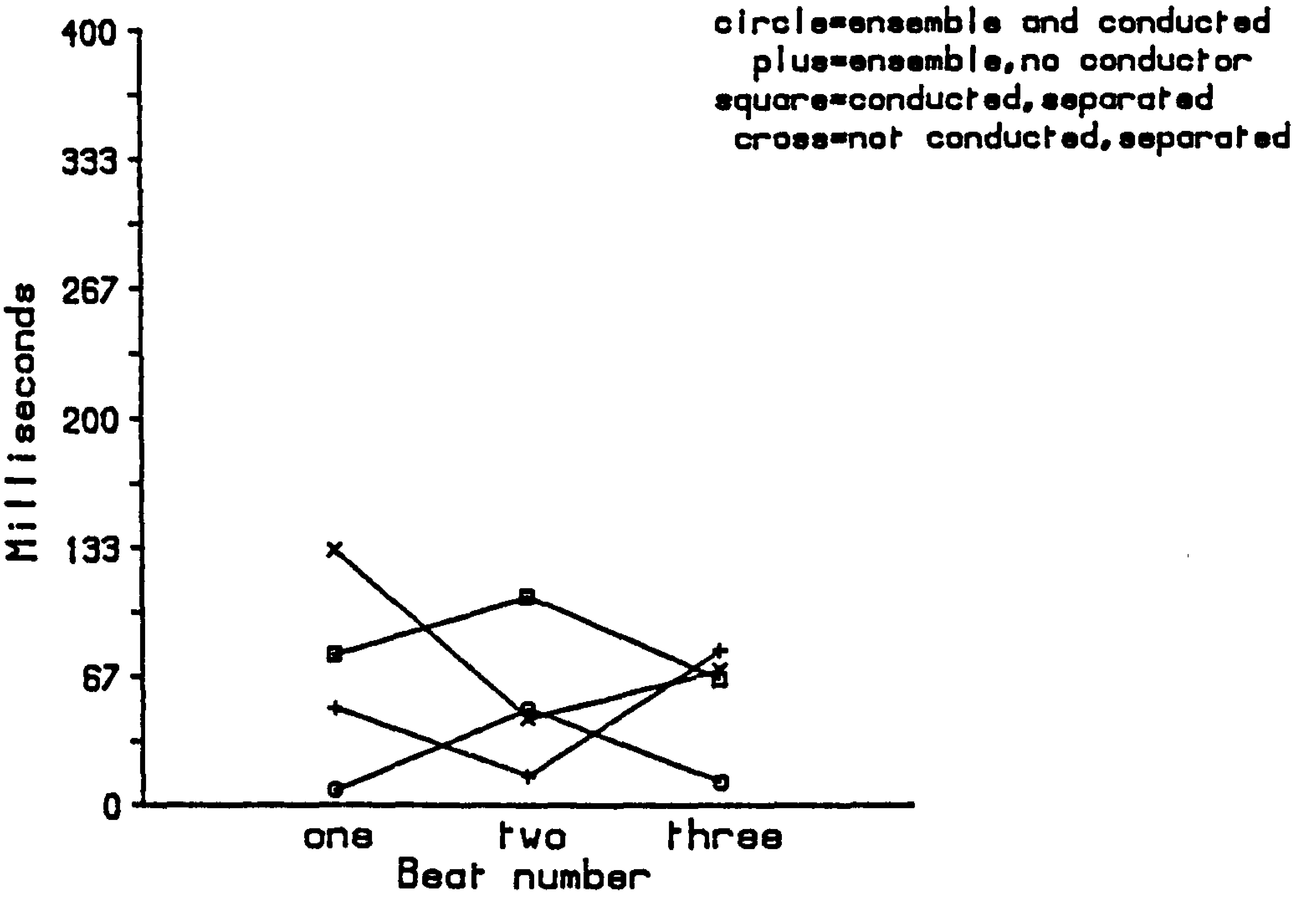
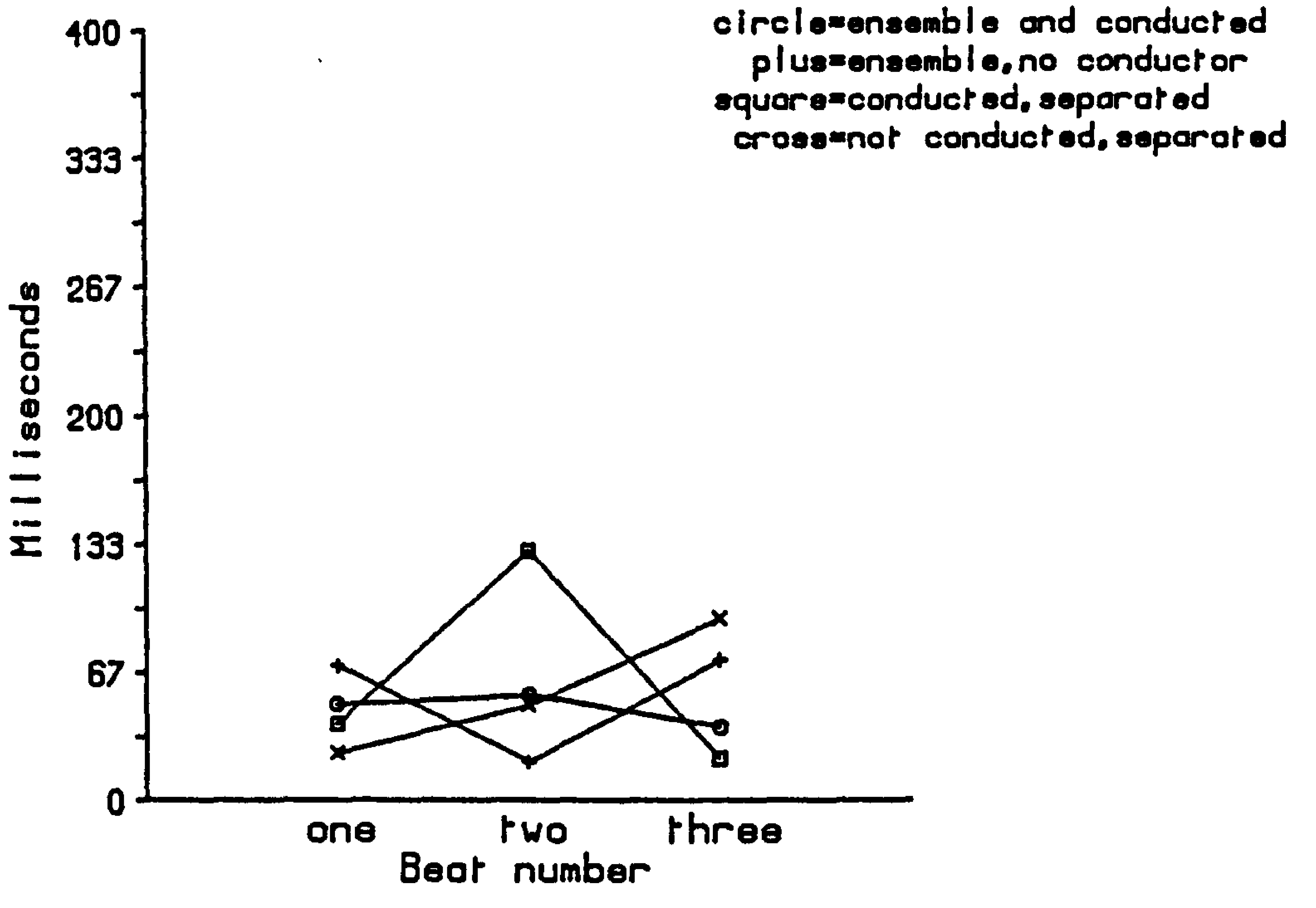


Figure 2.25
Ranges of differences
between drummers
At prestissimo



three in the ensemble and conducted condition, but this is an artifact. Analysis by tempo reveals that there is in actuality a general diminution of variance between beats one to two to three in this condition. There is a progressive decrease in the separated and not conducted condition, which is due to a large initial discrepancy and a random drift on two trials at larghetto. The ensemble, but not conducted condition and the separated but conducted condition mirror each other (both overall and at moderato and prestissimo separately) in that in the latter the largest range is on the second beat, while with the former the minimum range is on the second beat. When the players are ensemble but not conducted, the total variance on the first beat is similar to that on the third beat, so there is no overall trend, either over or by tempi. When the players are separated but conducted the variance on beats one and two is similar, so that the only feature is the reduction in variance by about 50% on the third beat both over and by tempi. This suggests that the continuing presence of the conductor does allow the players to regain temporal precision by the third beat, compensating for the absence of ensemble.

Summary of no-score series results

This is a complex situation. No single factor is adaquate to subsume observed variance, though that of ensemble is the most powerful, followed by tempo, then conductor. There is a learning effect over replicate and a compensation or hunting effect within trials which we can lose by converting the differences to absolute values. This 'averages out' the direction of the errors, and thus loses the identity of the drummers. The beat is the level of immediate control of discrepancies, as corrections are to successive beats. This correction process must be accomodated within an anticipatory, foreward planning structure, as the total range of beat discrepancies was well under reaction time (RT). There is a discussion of this point in chapter four. The minimal adaquate model is that of a ensemble * conducted interaction which varies across tempo.

Bartok series data

With the no-score data the variance profile was not clear. This is due to there being only three replications. With the Bartok data, no clear support for any model emerged with an ANOVA of differences between means, though replicate * beat * ensemble or beat + ensemble were suggested. While there were no consistent differences or shifts in mean inter-drummer differences for any of the factors, there were clear and consistent changes in the variability (accuracy) of their timing. In other words, the individual distribution means were similar but their variances were very different. Thus the variance profile provided the only clear analysis. This is partly because there were more replications, and less other structuring factors. The tempo factor is absent. The compensating effect over replicate does not appear in the Bartok data. This has two possible explanations. Either the additional complexity makes a conscious adjustment to subsequent trials more difficult, or else there is a "normalising" effect of the presence of a score.

The lack of a compensatory effect accounts for the fact that the result profile was not significantly affected by the conversion to absolute values, unlike the no-score data. The same factors emerge, with the same levels of significance. This is why the real values are discussed here. It was necessary to take the log of the variances to normalise the distributions, i.e. to transform sample variances into normal variates, before doing the ANOVA. The variance levels for the two factors that proved important, ensemble and beat, are illustrated in table nine, and in figures 2.26 and 2.27.

Table nine

Variance levels (ANOVA of log variances of 5 replicates)

Factor

(1) Ensemble

Level-	Yes	No	
Variance-	539.0	1328.3	
S.D.-	23.1	36.4	$P > 0.05$

(2) Beat

Beat Number-	one	two	three	four	five	six
Variance-	1098.0	486.0	1078.9	1938.0	1143.0	287.6
S.D.-	33.0	22.0	32.8	44.0	33.8	17.0

This just fails significance.

Main Factors

Ensemble

Variance increases by about 66% when the players are separated. This is shown in figure 2.27. Ensemble was the only factor to achieve significance independently, after collapsing across other conditions and replications.

Figure 2.26
ANOVA of log variances
of five replicates

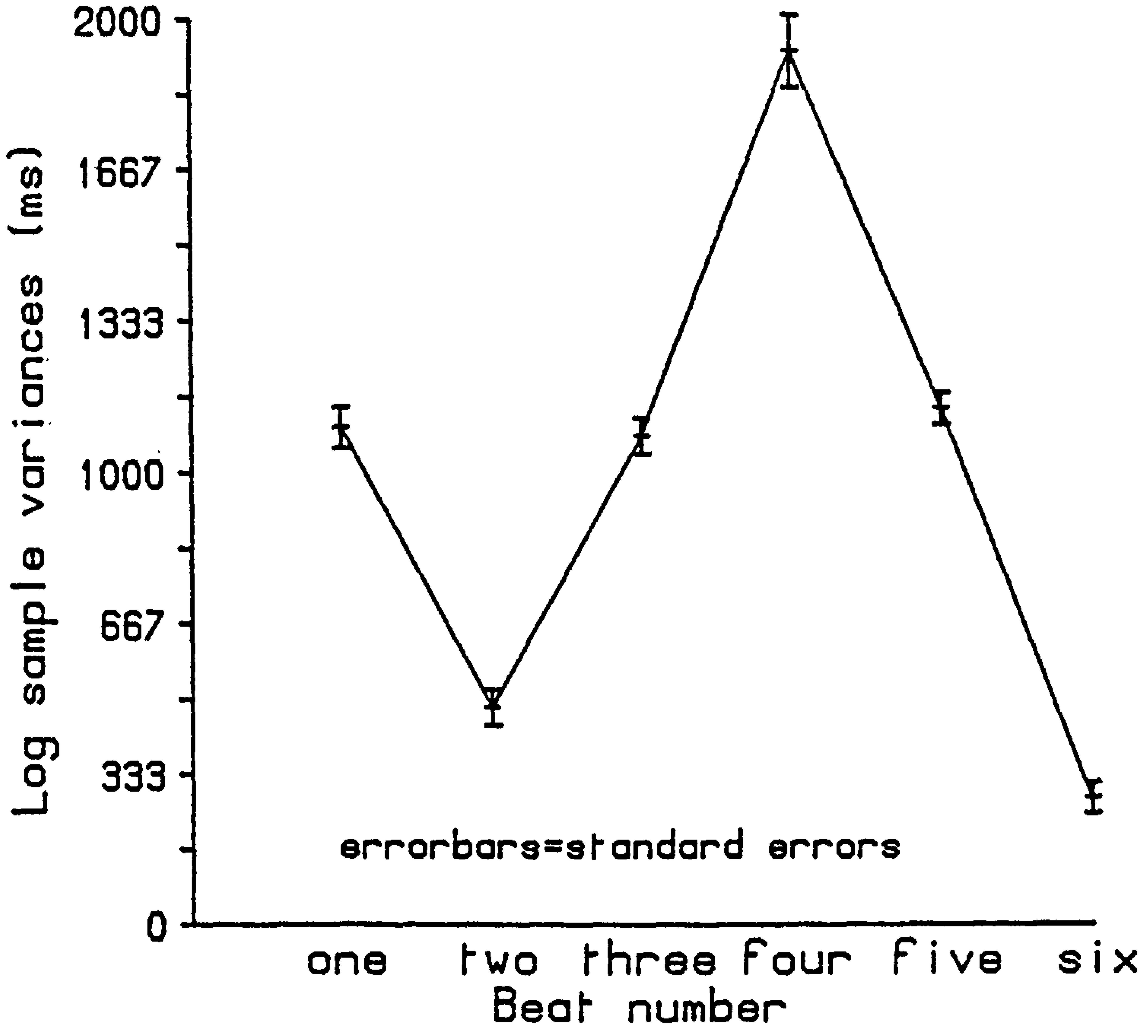
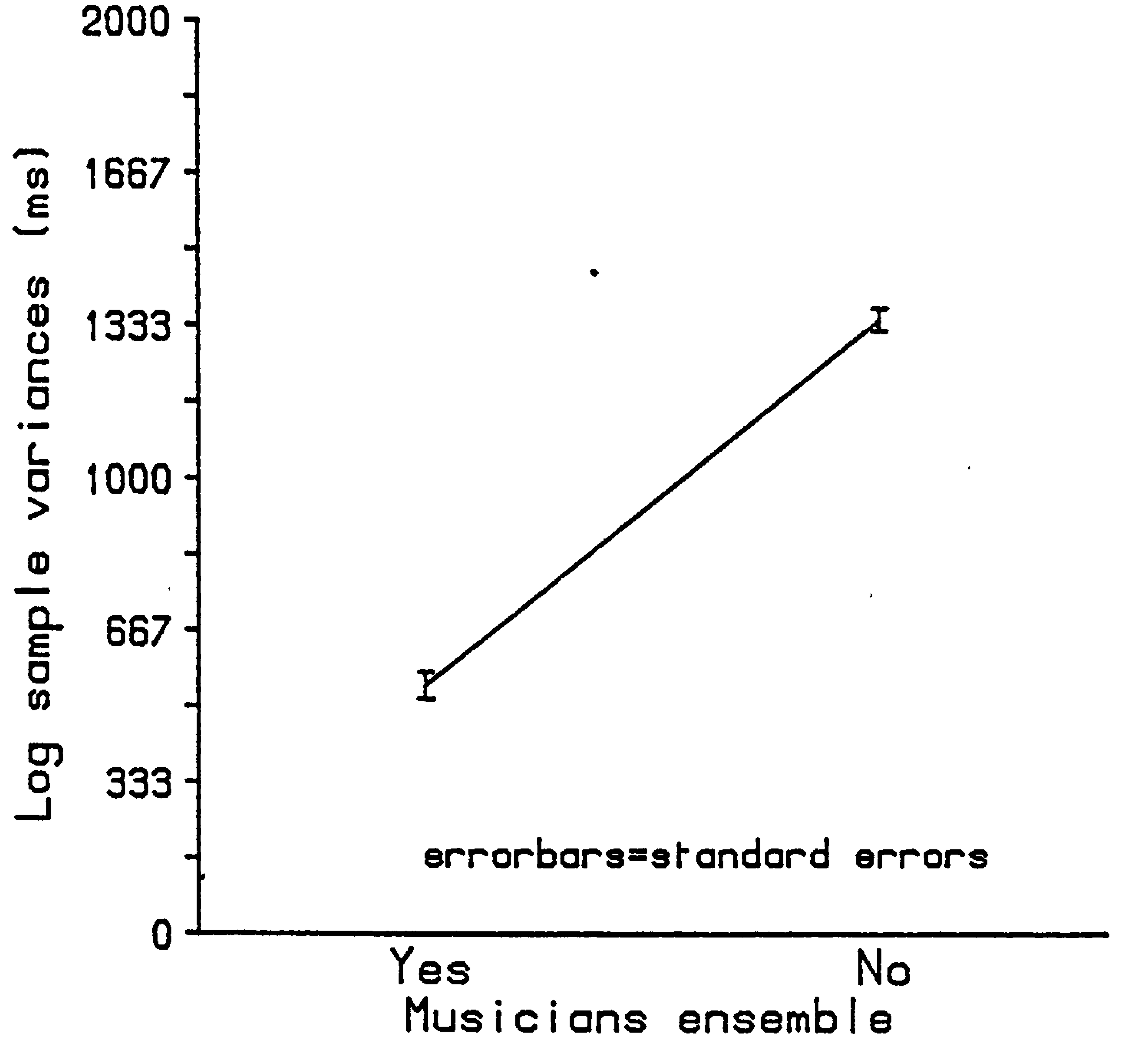


Figure 2.27
ANOVA of log variances
of five replicates



The conductor

Maximum variance does occur in the most deprived condition. This can be seen by comparing figure 2.31 with figure 2.28, 2.29, or 2.30. However, the presence or absence of the conductor does not emerge as a significant variable when considered alone. It is important in interaction. The interaction of the conductor and ensemble are shown in table ten.

Table ten

The interaction of conductor and ensemble.

	Ensemble	No Ensemble	All
Conducted	30	30	60
	-2.467	-0.267	-1.367
	28.632	31.580	29.906
Not Conducted	30	30	60
	0.567	-14.800	-7.117
	30.659	55.418.	45.074
All	60	60	120
	-0.950	-7.533	-4.242
	29.450	45.315	38.197

Cell contents.....count
mean
S.D.

Minor factors

Beat

The only other factor which comes close to significance is beat. This is obscured by ensemble but does not interact significantly. The variation across replicates, for each beat, by ensemble and conductor factors together, is shown in figures 2.28 to 2.31. The variation across beats by ensemble is given in table eleven, and the variation of beat by conductor is given in table twelve.

Table eleven

Ensemble and beat.

Beat No:-	one	two	three	four	five	six	All
Ensemble	10	10	10	10	10	10	60
	7.600	1.200	-16.600	1.500	-3.300	3.900	-0.950
	30.711	22.449	25.864	36.764	41.692	9.073	29.450
No ens	10	10	10	10	10	10	60
	8.000	-9.200	1.200	-30.000	-17.500	2.300	-7.533
	43.264	25.368	63.555	63.103	27.480	32.177	45.315
All	20	20	20	20	20	20	120
	7.800	-4.000	-7.700	-14.250	-10.400	3.100	-4.242
	36.516	23.917	48.100	52.797	35.130	23.024	38.197

Cell contents.....count
mean
S.D.

Table twelve

Conductor and beat.

Beat No:-	one	two	three	four	five	six	All
Conducted	10	10	10	10	10	10	60
	9.900	-1.700	-4.600	-15.800	-3.200	7.200	-1.367
	33.020	19.551	28.281	33.727	36.405	25.659	29.906
Not Cond	10	10	10	10	10	10	60
	5.700	-6.300	-10.800	-12.700	-17.600	-1.000	-7.117
	41.411	28.523	63.742	68.862	34.131	20.575	45.074
All	20	20	20	20	20	20	120
	7.800	-4.000	-7.700	-14.250	-10.400	3.100	-4.242
	36.516	23.917	48.100	52.797	35.130	23.024	38.197

Cell contents.....count
mean
S.D.

The total pattern in variance across the six beats is shown in table nine and in figure 2.26, having collapsed across ensemble and conductor. The differences are not significant, but note that the second and sixth beats stand out. It is not clear from the score (a copy of which is in appendix three) why the players should be less variable on these beats, but note that of the six synchronising beats, four are located first in the bar. The second and sixth are

Figure 2.28
Differences between drummers
ensemble and conducted

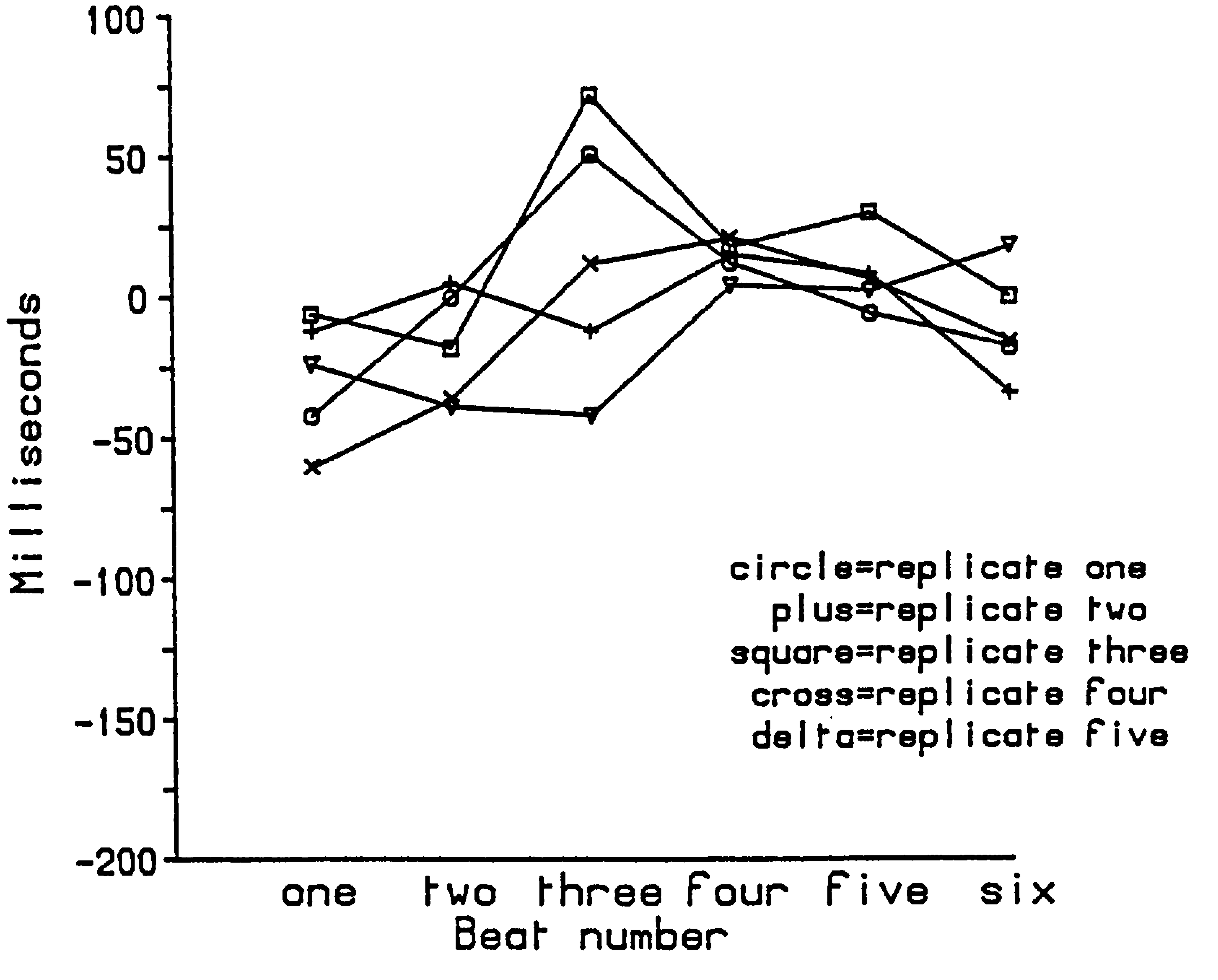


Figure 2.29
Differences between drummers
ensemble but not conducted

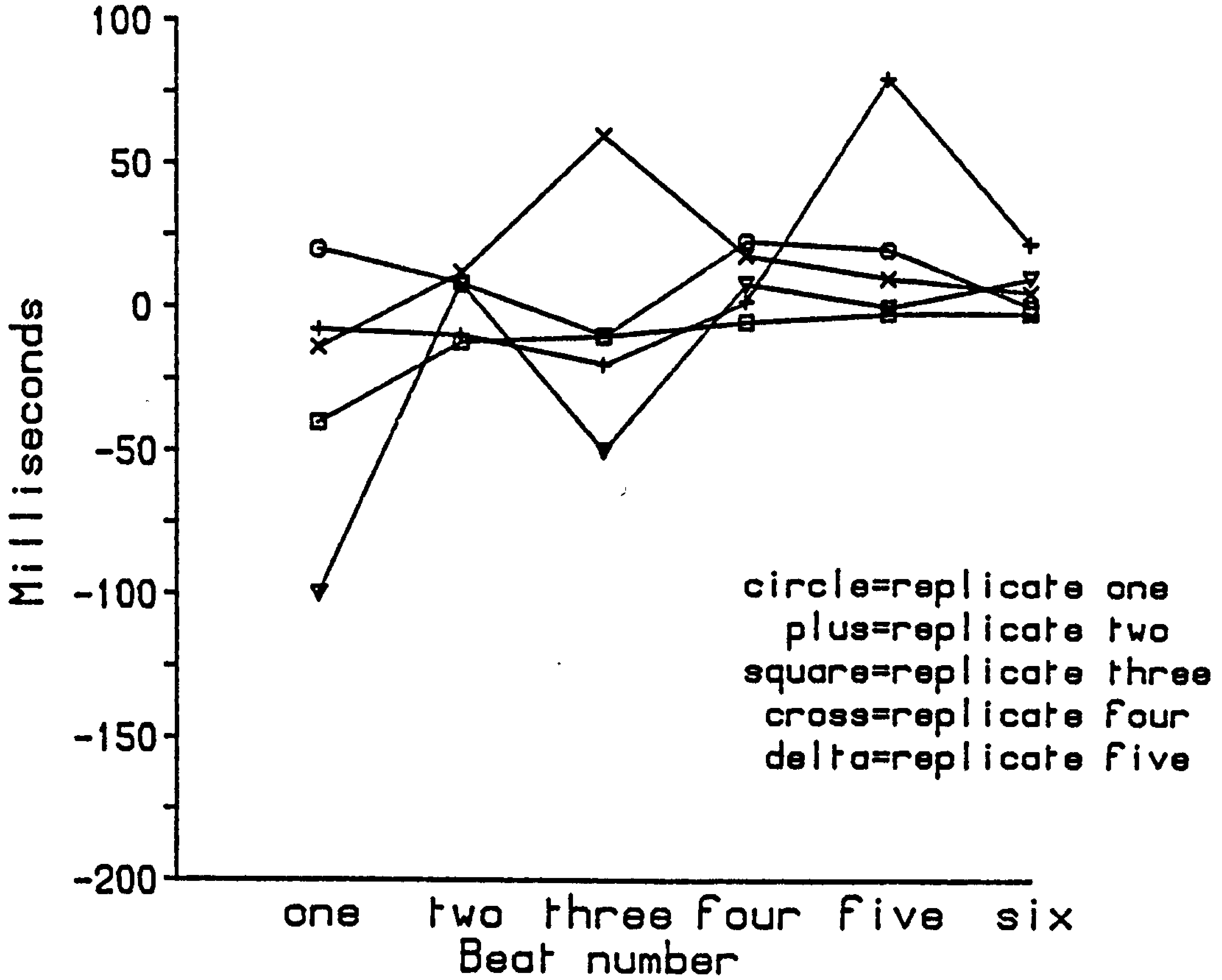


Figure 2.30
Differences between drummers
conducted but not ensemble

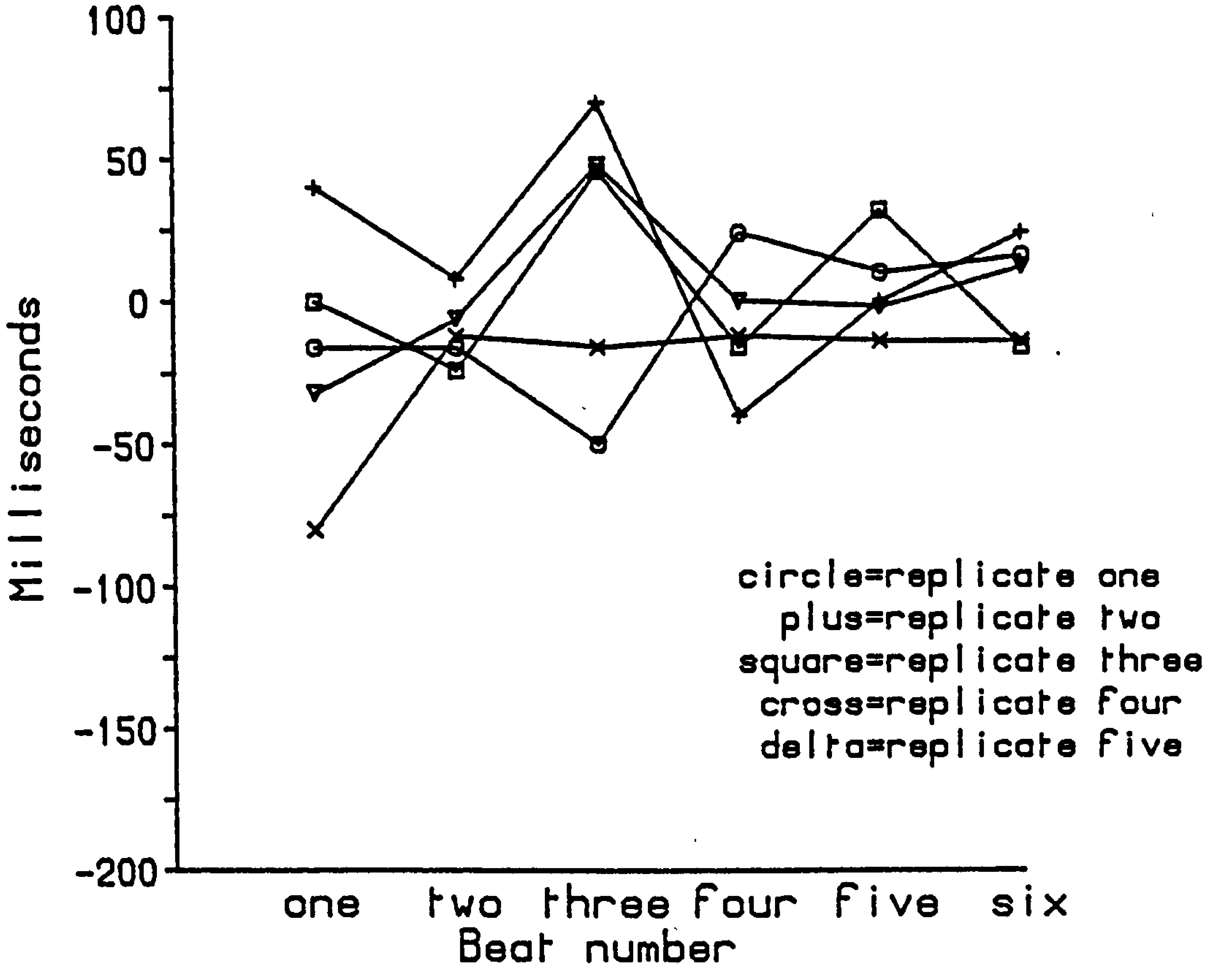
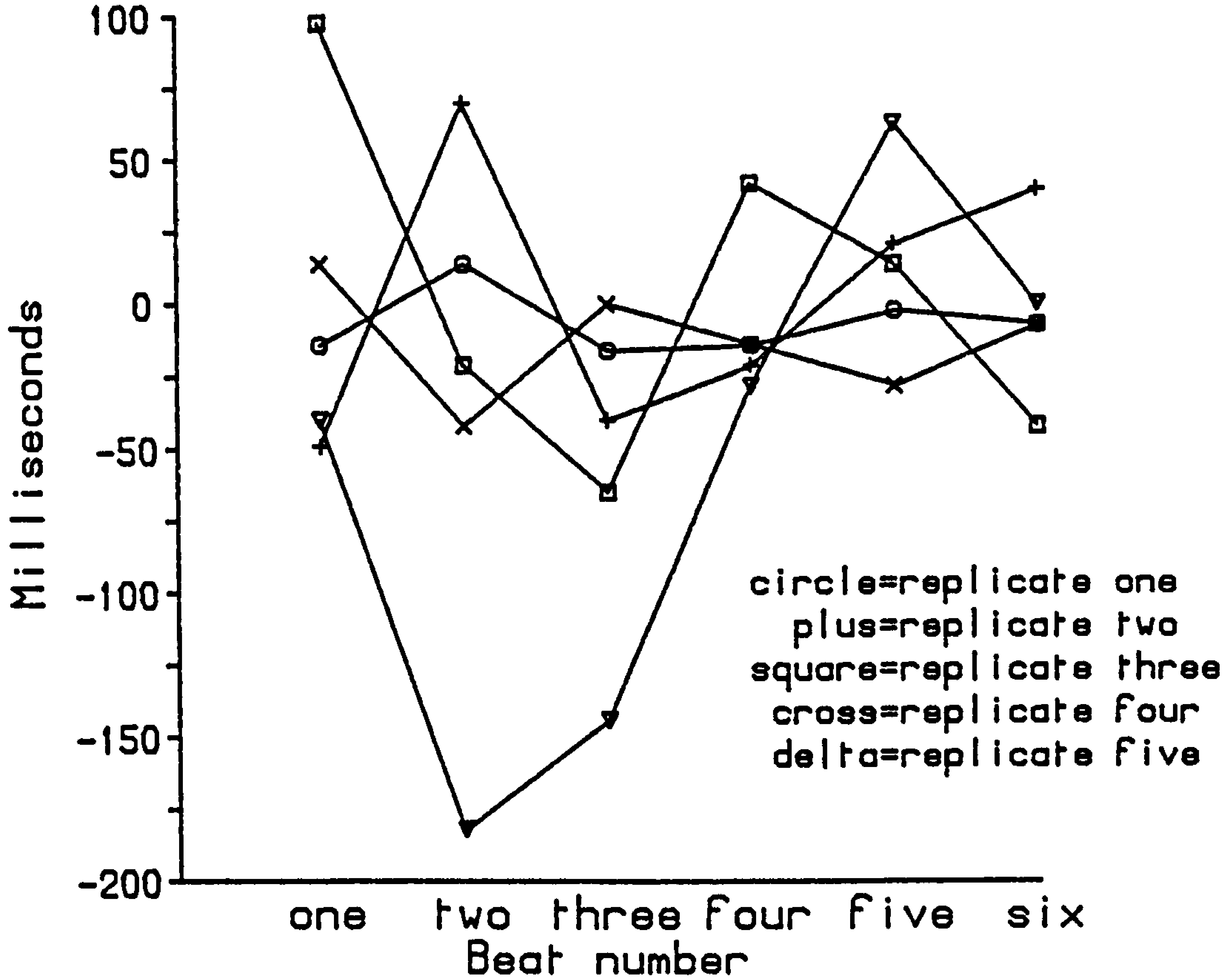


Figure 2.31
Differences between drummers
neither conducted nor ensemble



both located first in the bar, which may mean that they are more salient. Furthermore, maximum variance occurs on beat four, which is one of the two beats not located first in the bar. However, beat five, the other of that pair, has a variance similar to that on beats one and three, so the "salience" argument is weak. Table thirteen summarises which of the interactions of the two main factors (ensemble and conductor) and the most important minor factor (beat) are statistically significant.

<u>Table thirteen</u>

<u>Tests of significance</u>
Bartok series data, with the differences between the drummers in real values

Factor	F-Ratio	Significance Level
(1) two-way interactions		
(1) Conductor.Ensemble	1.4	Not sig. Becomes 1.5 when Ens.Cond added to residual
(2) Ensemble.Beat	1.3	Not sig. Becomes 1.47 when Ens.Cond added to residual
(2) Single factors		
(1) Conductor	1.12	Not sig
(2) Beat	2.08	Removal of two-way interactions reduces this to 1.9- not sig.
(3) Ensemble	5.34	0.1 > P > 0.05 Removal of two-way interactions reduces to 4.9- P > 0.05

<u>Overall task difficulty</u>

For each of the six beats the difficulty ranking of the four ensemble and conducted factor permutations is generally preserved, with the smallest ranges obtaining for the optimal ensemble and conducted condition, the largest for the most deprived separated and not conducted condition, with the no conductor and the separated conditions ranked in between. This is shown in table fourteen. The effect is weaker than in the no-score series. This is likely to be due to the fact that in the Bartok series a score is always present. This third source of information appears to mitigate the effects of the loss of either or both of the other sources, thus weakening the separation of the differences. This answers the third question of the introduction. The score is not sufficient to substitute for the other sources of information, but it serves to make the largest corrections unnecessary. The conducted factor is weakened much more than the ensemble factor, in terms of range and variation.

Table fourteen

ANOVA of ensemble and conducted factors

S.D.'s by beat, summed over replicate

		Beat one ensemble ? Yes	No	All	Beat two ensemble ? Yes	No	All	Beat three ensemble ? Yes	No	All
cond ?	Yes	41.4	26.8	33.0	15.1	23.9	19.6	16.6	23.8	28.3
	No	18.4	59.1	41.4	27.4	22.2	28.5	32.9	89.7	63.7
	All	30.7	43.3	36.5	22.4	25.4	23.9	25.9	63.6	48.1

		Beat four ensemble ? Yes	No	All	Beat five ensemble ? Yes	No	All	Beat six ensemble ? Yes	No	All
cond ?	Yes	31.6	39.5	33.7	32.8	34.9	36.4	11.7	36.6	25.7
	No	36.2	83.1	68.9	46.3	21.6	34.1	6.5	29.7	20.6
	All	36.8	63.1	52.8	41.7	27.5	35.1	9.1	32.2	23.0

The order of difficulty ranking is clearest on beats two, three, and four. On the first beat it is necessary to collapse across the conducted factor to see any effect of ensemble. On the second beat the ensemble* conducted interaction comes close to significant, even though some of the components lie in the reverse order. Beat five shows an even stronger effect of the ensemble * conducted interaction, but it lies in the reverse direction. Beat six compromises, with variance ranking lying in the right direction for ensemble (smaller with than without), and in the reverse direction for the conducted factor (smaller without than with).

With either absolute values, or real means, the result profile is much less clear than with variances. With absolute values, for the individual beats, the only significant factors are the ensemble * conducted interaction on beat one and ensemble on beat six. With real values, there is little consistent difference between the means. The ensemble * conducted interaction on beat two is the only one to achieve significance.

Summary and conclusions

The main points are these:

(1) Ensemble

The most powerful factor is ensemble. The timing accuracy of the musicians is approximately 75% worse if they are separated from each other than if they receive no further guidance from the conductor. Therefore ensemble is more important than the conductor as a source of timing information.

As Clark (cello, Philharmonia) puts it, talking about Klemperer.

> "..he did know how to conduct. His beat was'nt good, but it was usually within half a beat of the right place. Well, I never took any notice of the beat, I just followed the music."

This would explain why players can spend as much time as they do looking at their scores, referring to the conductor preferentially at moments which require sections of the orchestra to be coordinated with each other.

The conductor

The presence of the conductor improves temporal precision, but to a lesser extent than ensemble. As the conductor gives the first beat in all conditions, the large initial discrepancies and subsequent drift observed when the players were separated, and the conductor gave no further information, means that the players read different tempi and start times from the conductor.

When the players were separated, but the conductor was still present, the largest range was obtained for beat two in the no-score series, but the players had recovered and improved on their initial accuracy by beat three. This suggests that they read the start time approximately correctly but differed on the reading of the tempo. However, the continuing presence of the conductor allowed them to re-synchronise.

The conclusion is that the derivation of tempo and start time are different processes, and that there is an ambiguity inherent in the conductor's actions. This suggests that the important job for the players is to synchronise with each other on the first beat, rather than with the conductor.

This makes sense, given that what the audience hear are the audible asynchronies. The conductor's baton is

"the one instrument that doesn't make a sound."

In fact, Previn (1979) points out that as a result of this fact, the orchestra can suffer more at the hands of the conductor than vice-versa, with these words.

> "The baton is silent, but if the mistake of the wielder of the baton results in a clarinet player's wrong entrance, why, surely, it will be the clarinet player who is faulted by the listeners."

Finally, when the conductor's beat - first drummer's beat difference is taken as the dependent variable, it becomes clear that when the players are not separated, they ignore the conductor to a substantial extent- they are forced to stick much more closely to the conductor's times when they are deprived of ensemble. The latter finding means that the players can derive accurate timing from the conductor, but generally do not.

Conclusions (1) and (2) together suggest that ensemble is crucial for precise timing control, and the normal role of the conductor is to give general or "ballpark" rather than specific temporal guidance.

Tempo

The slower the tempo, the larger the discrepancies in beat placing. Similarly, Carlton et al (1983) found that timing error decreased as a log function of increase in the mean velocity of movements. Newell et al (1979), and Newell (1980), and Newell et al (1980) found that this relationship was largely independent of movement time and distance. Carlton et al contrast two explanatory models. The first is that proposed by Milner-Brown et al (1973), who obtained evidence that more motor units are deployed in making faster movements. Slower movements therefore employ fewer units, and Milner-Brown et al suggest that the difficulty lies in having to consistently structure and initiate a smaller selection of units. The second model is that the smaller number of units deployed have more difficulty in overcoming the friction and inertia of the system. Falkenberg and Newell (1980) and Carlton et al established that the first model is correct. The relationship between tempo and accuracy therefore appears to be an organisational level problem, rather than reflecting the accuracy of the motor units per se. This interpretation is disputed by Schmidt et al (1979), so cannot be considered to be the final word.

The presence of either the conductor or the other player allows corrections to occur, and these counteract the effect of tempo to a large extent.

(4) Compensating and adjusting

(a) within trials- this effect occurs in almost all trials when there is no assignation of roles. This suggests that the players become engaged in a continuous tracking and monitoring process. The possibility of corrections depends on the presence of either the other player or the conductor.

(b) across replicates- this can only be a cognitive effect, involving memory. This effect does not occur when a score is present, thus the effect of a score is to make major adjustments unecessary. This could be due either to a direct effect of the score, in constraining the temporal and physical parameters of the performance, or an indirect effect, with the greater consistency resulting from the more realistic and musical nature of the task with a score.

Discussion

(1) What is ensemble?

The Harvard Dictionary of Music provides the following two definitions.

(1) By Willaert's sixteenth century definition: ensemble is a definitive term referring to a group of instruments. It should be noted that choral and instrumental ensemble are not, then, entirely equivalent terms.

(2) The balance and unification obtained in performance. This is our current interest.

The Concise Oxford Dictionary of Music (Scholes edition) notes that ensemble is the French word for being together, and gives a similar pair of definitions.

(1) Any combination of instruments in a performance, especially where the music is written for parts or voices and each instrument takes one voice.

(2) "Quality in performance, implying the greater or lesser exhibition of the cooperative spirit with unanimity of attack, "give and take", and balance of tone: so such expressions as good ensemble and poor ensemble. "

(2) Why is ensemble necessary?

McElheren (1966) has estimated that during a piece, good players spend at least two to three seconds at a time looking at their score. Less confident musicians spend even more time with their heads in the score. It therefore follows that once the tempo has been set and the start successfully synchronised, the players attain some independence from the conductor. We cannot yet deduce absolute independence, as there remains the possibility that musicians monitor the outline of the baton trajectory with peripheral vision. However, we can make the distinction between precise timing with respect to the conductor, which could not occur, and timing with respect to the other players (ensemble), which must not be lost as the discrepancies would be audible. Therefore the "ensemble" of an orchestra is an internal dynamic that enables an experienced orchestra to play extensive sections of pieces in their normal repertoire without requiring to constantly orient themselves with respect to the conductor.

(3) <u>What is the relationship between sources of timing information?</u>

<u>The conductor</u>

The conductor's most crucial timekeeping moments occur at (a) the start, when he must get everybody in at the same time and off at the same rate, (b) when bringing in sections after rests (which is a similar task) and (c) when cutting off fermatas. Anecdotal evidence suggests that at other times the orchestra rely on each other and the established rhythm to keep in time, at least as much as on the conductor. Results of this experiment support an even stronger demarcation of priorities. Certainly, there are moments when the conductor himself relies on the orchestra to find the place again. Previn quotes this advice to him from Tucknell, principal horn with the LSO.

> "When you get lost, and you will, everbody does at one time or another, just make some elegant vague motions and we'll put it all to rights quickly enough. But for God's sake don't lose your nerve and start flogging away at us, then we'll get lost too and everybody's in trouble."

Beecham occasionally got lost. The orchestra would know because he would make a windmilling motion until he found the place again. He made a point of keeping on good terms with the trombones, upon whom he relied for clear and loud entries to remind him of the place. As the orchestra did not disintegrate, they must have been able to rely on their ensemble.

Richard Strauss once advised aspiring conductors, rather cynically, to

> "..put your left thumb in your waistcoat, and just follow the orchestra with your right. It is the audience who should sweat, not the conductor."

There is also a special "ensemble" that occurs at the start. This is often referred to as "breathing". The orchestra breathe in sharply on the upbeat, hold the breath at its maximum for a fraction of a second at the top of the upbeat, then exhale on the downbeat. This is an event without precise definition of its beginning and end but with a perceptual centre or turnaround (the maximum inhalation) which is ideally synchronised with the apex of the baton movement. This intake of breath is audible to the conductor, and tells him where the orchestra are, and therefore where they think he is. The musicians provide visual cues too. Their heads lift, their chests inflate, their instruments (bows, or sticks) rise, peak at the top of the upbeat, then drop on the downbeat onto the first beat.

There is a more general need for musicians to monitor the conductor, as any piece of music will vary between renditions. The assigned time intervals will not be exactly the same. Without even a rubato, the dynamic of the music will be slightly varied to accent subtly different possibilities. This process may be almost unconscious. Different moods will be manifested in different interpretations, yet within the temporal constraint of the score. There are often qualitative and quantitative differences between rehearsals and performances. McElheren remarks that while during rehearsal it was necessary to concentrate on the detail of a piece, during performances he could concentrate on the music per se. He would sometimes then see a new dimension of the music, and take a section at a new tempo or vary the timing relative to the rehearsal version. Abbado often takes a piece faster in performances than in rehearsal. This requires a very fast response from the players, which is the main reason why he does this- to keep them at peak alertness. Beecham also said that the secret of a good performance was to keep the players alert. He would notate additional dynamics on the scores of various instrumentalists after the final rehearsal so that they would discover them only during the actual performance. These techniques and tricks are ways in which a conductor can make the orchestra alert and responsive to the degree that it can correctly anticipate and achieve the precise degree of synchrony required.

There are also different circumstances in which it will be necessary to monitor either the conductor or the orchestra in preference. Kettel (timpani and percussion, LSO) comments that

> "..if cellos are playing with drums, they don't listen to the downbeat, they follow the conductor...going with the beat is sometimes wrong...the rhythm is going chuk, chuk, chuk in their ears, and the fellows are still sitting with eyes riveted on the conductor."

McElheren points out that it is, in fact, almost impossible for an orchestra to ignore a conductor, and describes how if a conductor deliberately makes his gestures incompatible with the orchestra's beat the performance will immediately deteriorate. Mehta, in a conducting masterclass, noticed that one of his pupils had evidently been practicing to records. His technique had not adapted to the orchestra in front of him. Mehta insisted that the conductor's job was to engage in a dialogue with the orchestra, and to be responsive to their contribution. At the other extreme, Galway claims that on one occasion Karajan (who sometimes conducts with his eyes closed) was conducting Beethoven's Fifth with the Berlin Philharmonic when the hall lights fused. The orchestra, who knew the piece well, played on. A few minutes later the lights were restored, and there was Karajan, still conducting, apparently having not noticed a thing.

Ensemble is therefore not a substitute for every function of the conductor, although there is the (probably apocryphal) story of the musician on his way home from the Proms who was asked who the conductor had been, and claimed he didn't know because he had'nt looked.

The internal timing

The independence of the musicians from the conductor also means that each player must have an independent programmable clock with an inter-event interval which can be set to an external criterion, which could be the timing of the other players or the conductor. Shaffer (1982) has presented a similar argument for the existence of an internal clock. It must also be that this clock can not only be programmed as to rate but can also be set to start on or near the beat derived from the conductor's introductory upbeat and downbeat. This distinction between entrainment and synchronisation is examined in chapter eight. Shaffer (1982) has pointed out that this clock could then serve either to trigger events or to target events. If movement-targetting correctly describes what occurs at the initial beat, (see chapter four) then it is parsimonious to postulate, within the framework of the model, that the same principle of targetting applies in continuous beat-matching.

The level of responsiveness of the orchestral players also implies that the clock must be stochastic in nature, providing tendencies rather than metronomically precise set intervals, as the clock rate must be responsive to advance cues from the conductor and other players. This would allow the orchestra to respond flexibly in their progress through the overall schematic structure of the piece. They may be called upon not simply to to scale the timing up, or down, by some defined factor, but even to incorporate small variations on the beat structure as previously rehearsed: for example varying the rubato (see chapter three) or taking a "breath" in the music in a slightly different place. This is one reason why the musician must have an independent clock. Once the clock was set and started, the musician could then rely on this source alone for several moments, and monitor the conductor. It also would allow time to look at the score should a reminder of the notes be necessary. In the last section, however, it became clear that musicians are not independent of the conductor and should not look down for too long. McElheren describes several exercises in slight unexpected tempo changes to ensure that the orchestra is properly monitoring the conductor and therefore able to respond with the rapidity required. This can be within a fraction of a beat; if the conductor gives a sudden extra large upbeat, the increased accent indicated is to fall on the next beat. The degree of responsiveness cultivated by players can be seen in a trick played by the LSO strings on Kyung-wha Chung. She was sitting waiting for Previn to start the Tchaikovsky Violin Concerto, when the violins unbidden played the opening of a Mendelssohn Concerto. Such were her reflexes, she did not think of it as being wrong but sprang into action.

Thus although the players, individually and as an ensemble, have some independence, in essence they are still bound to the conductor- the man who, during the performance, is "driving the engine" (Boult (1963)).

Chapter Three

The Nature of the Beat

Abstract

The conductor's baton is in continuous motion, yet conveys a series of points in time. The feature of the baton trajectory that is used to communicate the beat proved to be the minima in the vertical axis of the baton position. The method used to record the times of the beats also revealed that the baton conveyed a structured beat, while the feet of the conductor and the violinist tapped regular intervals. The violinist in part deviated from the regular interval towards the pattern indicated by the conductor, thus indicating that the process of coordination of actions may be based on a regular rhythm, but remains dynamic and interactive.

Introduction

This chapter concerns the unit of timing involved in music, and the definition in physical terms of the beat.

A beat is an experiential event. It is more than a periodic demarcation of time, as it clearly has a definite psychological reality while not conforming to strict isochrony. However, as conductors communicate beats with a baton in continuous motion, it must be possible to evolve a practical definition of a beat in terms of features of movement. To do so, it was necessary to develop an alternative index of beat location, independent of the baton trajectory, which could then be used to identify the part of the baton trajectory that corresponded to the beat.

The first attempt to do so involved an extensive series of pilot projects. These involved Selspot-recording the cellist and the conductor of a string quartet, with synchronised and timed video to permit visual inspection of ambiguous points in the Selspot record in the analysis, and tape-recording the music on one track of a two-track tape. The other channel recorded the clock pulse of the Selspot system. The tape was then played back, an analogue to digital (A-D) converter relayed the signal to a PDP11 computer, where a timing program utilised the pulses as a clock reference. Meanwhile, the cellist listened to the music on the other track and tapped a switch on the beats. The switch closed a circuit through the A-D converter, and the program noted times of occurrence of taps in terms of number of Selspot pulses from the start of recording.

This was in order to be able to synchonise the times of the taps with the Selspot and video recorded events, and thus defining the beats.

Multiple tapping trials were recorded and analysed. Inter-trial reliability was found to be below the level of inter-subject precision observed with Selspot recording alone. Thus it appeared that to add the taps after the music was played was a different task from recording the beats as the music was being played. The multiple stages of the recording procedure may have added to the difficulty, as there were multiple potential sources of error.

It was concluded that the subjects should indicate the location of the beat while actually playing, in as natural and spontaneous a way as possible. As musicians often tap their feet while playing, to help carry the rhythm, the obvious choice was to utilise this and to design foot-tap switches. These were then linked to a Selspot light-emitting diode (LED), so that the times of switch closure were in the same record as the visual events.

These switches had to provide a clear sound, in order that the player should have accurate feedback as to where the tap occured. It was also necessary to ensure that neither subject could hear the foot-switch of the other subject being operated, in order to exclude the possibility that subjects might simply match foot taps. This required that the subjects be put in separate rooms, connected by closed-circuit television (CCTV). This allowed control of the sound and visual information available to both subjects. This also allowed the posing of a corollary question, namely, would the musician see the beat in the same place as the conductor indicated it to be?

The experience of following a conductor on live CCTV is not unknown in music. Organists may have to sit with their backs towards the conductor, or players may be seated in another room to get the effect of a distant sound, and in these cases CCTV is sometimes used (Previn (1979)). The subjects did not find it a difficult situation.

Methods

(1) Subjects

There were two subjects in these experiments, GT and SH. GT was the conductor, SH a violinist.

(2) Information available to subjects

The subjects sat in separate rooms, out of audible range of each other. A double CCTV system relayed live images both ways, but sound only from the violinist to the conductor. The sound was from a contact microphone on the sound body of the violin. This was designed to pick up the sound of the instrument without relaying the clicking of the violinist's tap switch.

(3) Data recording

(a) The Selspot movement monitoring system was used to record the position of two LED's. One was affixed to the baton tip, the other was secured to the desk top in front of the conductor, facing the cameras. The CCTV camera in the conductor's room was set immediately over the Selspot camera, so that they recorded virtually the same view. The cameras were set in the fronto-parallel plane, so that the axes of the recording correspond to true axes.

(b) Each subject had, under their preferred foot, a spring-loaded foot switch. These are illustrated in figure 3.1. The spring loading was adjusted to give a firm, positive feel to the foot tapping action, without being at all stiff. An electrical

1 cm
DOUBLE SPRINGS
BOLT (ELECTRICAL CONTACT)
DOWEL
BOLT (ELECTRICAL CONTACT)
HINGE
30 cm

contact was closed as two steel bolts, one on the base plate and the other on the top plate, clicked together. The bolt heads were ground off square to each other. This ensured a clean contact and a crisp click, to provide reliable feedback to the musicians. As each contact closed, it switched the desk top LED for a pre-set period. The conductor's foot switch operated the LED nominally for one frame, although it could operate over a frame boundary and appear as two frames in the recording. This required that the violinist's foot switch be set to operate the LED for three frames (though this could overlap into four) in order that it should always be possible to distinguish the order in which the subjects had tapped. Only when the taps followed directly one after the other was it impossible to determine the tap order, and this was recorded as if the taps had completely ovelapped.

(4) Recording Procedure

The start of each recording was signalled by a tone. The conductor would then give one full introductory bar before the first downbeat. Each recording lasted 61.45 seconds. The data was recorded by a PDP11 minicomputer.

(5) Music

The music selected for these experiments was Bartok's Soldatenlied and his Hinke-Tanz, numbers 15 and 27 in the U.E. 104526 edition of Bartok's 44 Duos. copies of these scores are in appendix three. They were chosen for the following reasons.

(1) The Soldatenlied is in 3:4, the Hinke-Tanz in 2:4, giving two time signatures for comparison.

(2) The Soldatenlied contains an accelerando, the Hinke-Tanz contains a ritardando (which was extended forwards to start at bar 21, to give an equal duration of tempo change), giving the two directions of tempo change.

(3) The two pieces are otherwise of approximately equal complexity.

(6) Trials

Each piece was played twice, giving four data sets for analysis.

(7) Analysis

There were two stages in the analysis.

Firstly, to find the aspect of the baton movement that gave the most accurate and consistent indication of beat location. To do this, it was necessary to define the aspect of movement that might be used as an index of the beat, and then to define a precise feature of each index as the representation of the beat itself. The selection of the precise feature was done by examining the vicinity of each pair of taps, and selecting an identifiable point around which sequences of taps clustered.

Secondly, to analyse the musical performance in terms of the accuracy achieved with respect to the beat index that emerged from the first stage.

In the first stage, the best trials were selected for analysis.

These were the second attempts in both cases, which were reported by the musicians to be better performances. With the Soldatenlied, the conductor's introductory bar and the first eight bars, up to the start of the accelerando, were selected for detailed examination, as this includes the longest section of the piece without changes in volume, or tempo, or time signature. Similarly, with the Hinke-Tanz, the introductory bar and the first eight bars were selected, in order to have a section of comparable length, and also because the violinist rests in the ninth bar.

In the second stage of the analysis, every part of all four trials was used.

The aspects of the baton movement that were selected for comparison, and the points selected as the precise beat location, were as follows (all are illustrated in figures 3.2 to 3.7).

(a) The position in the vertical (Y) axis of the baton. The index was the minimum position.

(b) The Y component of the velocity of the baton, obtained by differentiating (a). The index was the negative to positive transition.

(c) The Y component of the acceleration of the baton, obtained by differentiation of (b). The index was the peak acceleration.

(d) The absolute velocity of the baton, that is, the square root of the sum of squares of the horizontal (X) and the Y axis components of velocity. Two indices were used here, as the taps tended to occur in the middle of a rise: the start of the rise, and the subsequent peak.

(e) The absolute acceleration of the baton. The procedure for obtaining this is similar to that of (d), save only that accelerations are used, instead of velocities. The index was the start of the principal rise.

(f) The rate of change of absolute velocity. This requires following the procedure for (d), then differentiating the resultant. The index was the maximum value.

After processing the time series, it was necessary in every case to smooth the resultant in order to clarify the main trends. This was done with a symmetrical noncausative Gaussian filter, with a sampling window set to five frames, or 16ms. Three passes were required.

The differences between the indices is generally clear, but confusion can arise with (e) and (f). This is because when the baton is moving in a straight line, in any direction, (e) = (f) = 0 as long as the speed is held constant. However, both will be non-zero when the baton is travelling in a curve at varying speed, and (e) will be non-zero while (f) = 0 if the baton travels in a curve with constant speed. The faster the travel and the tighter the curve, the larger (e) will be.

FIGURE 3.2 MINIMA IN Y AXIS

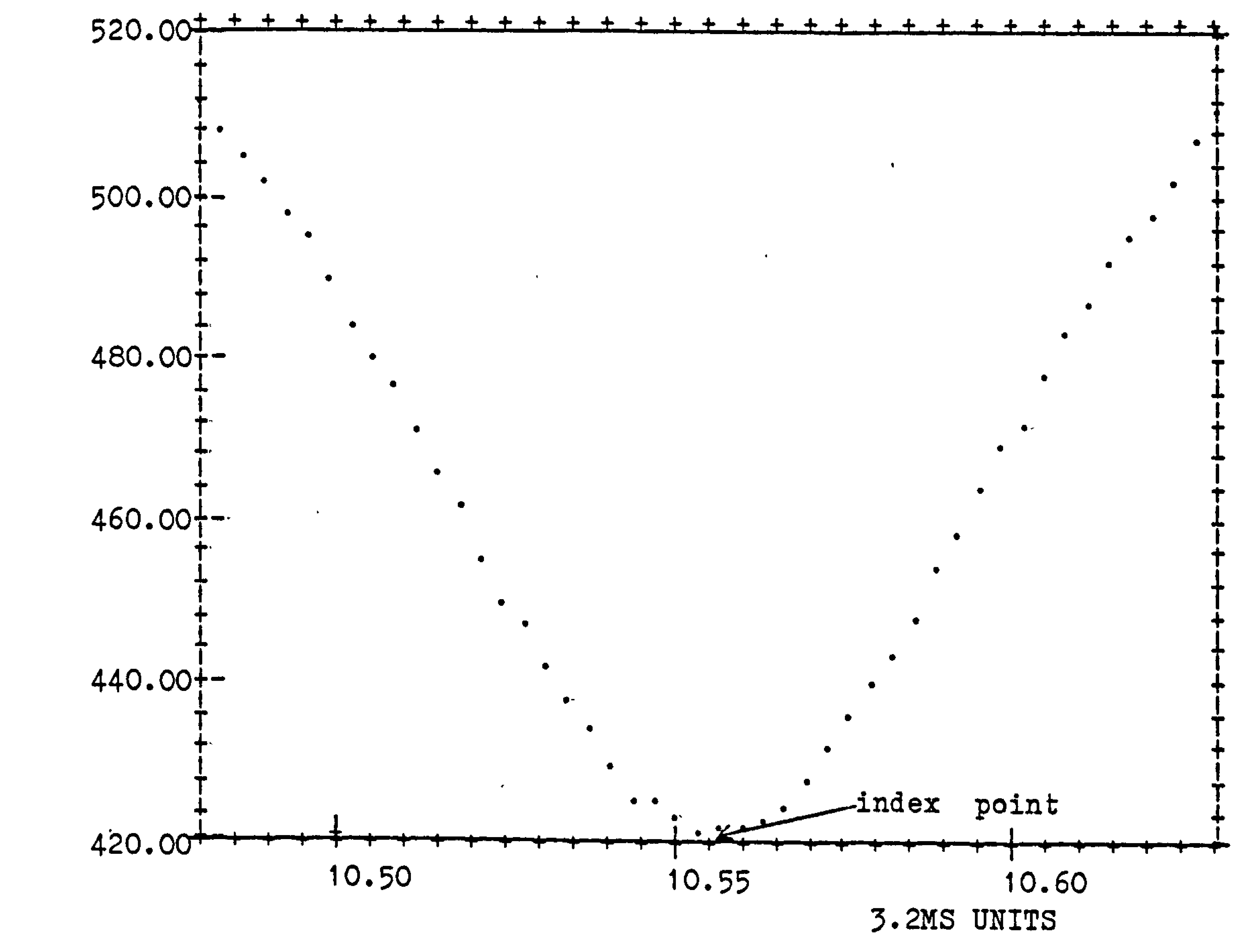


FIGURE 3.3 - TO + VELOCITY TRANSITION

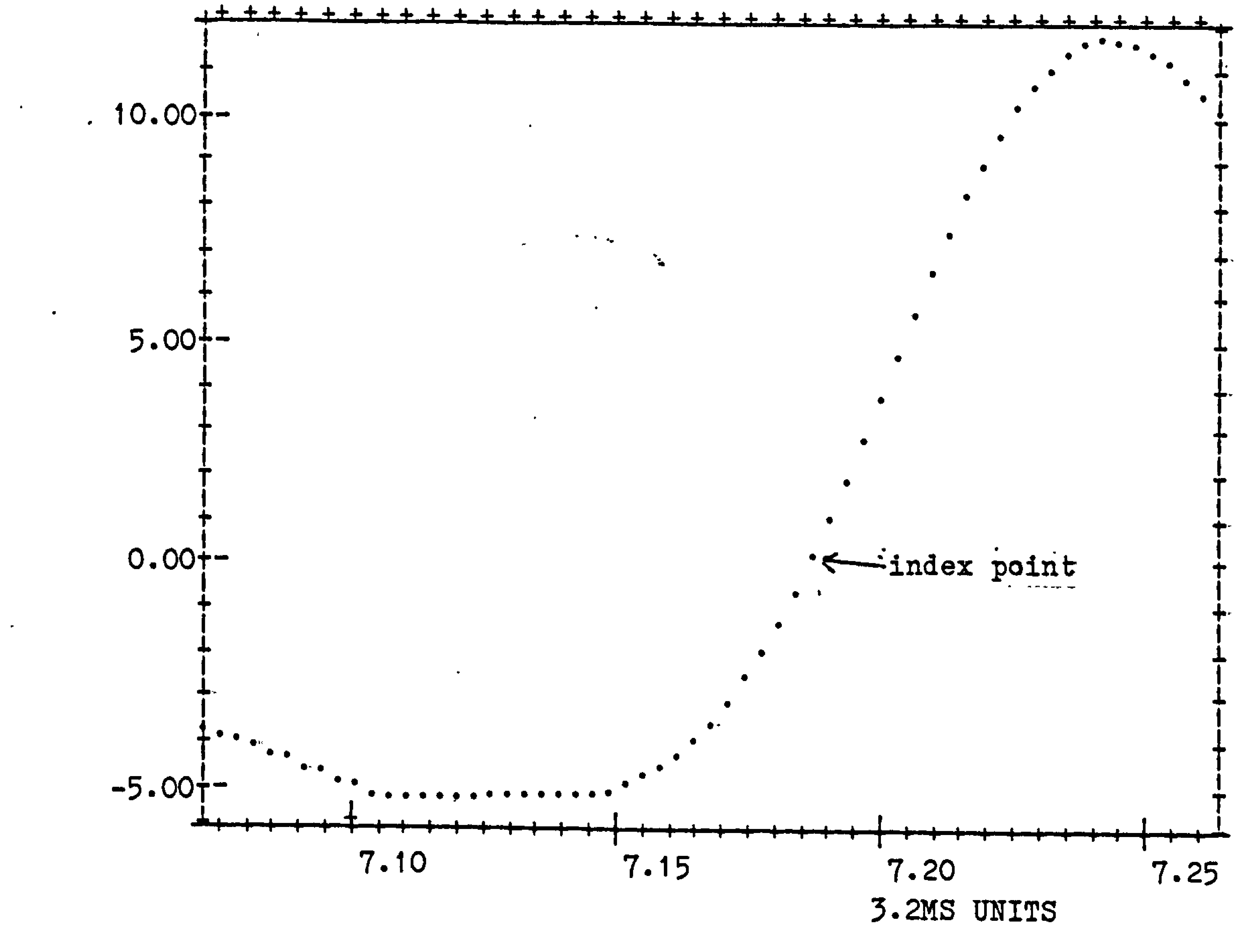


FIGURE 3.4 PEAK Y AXIS ACCELERATION

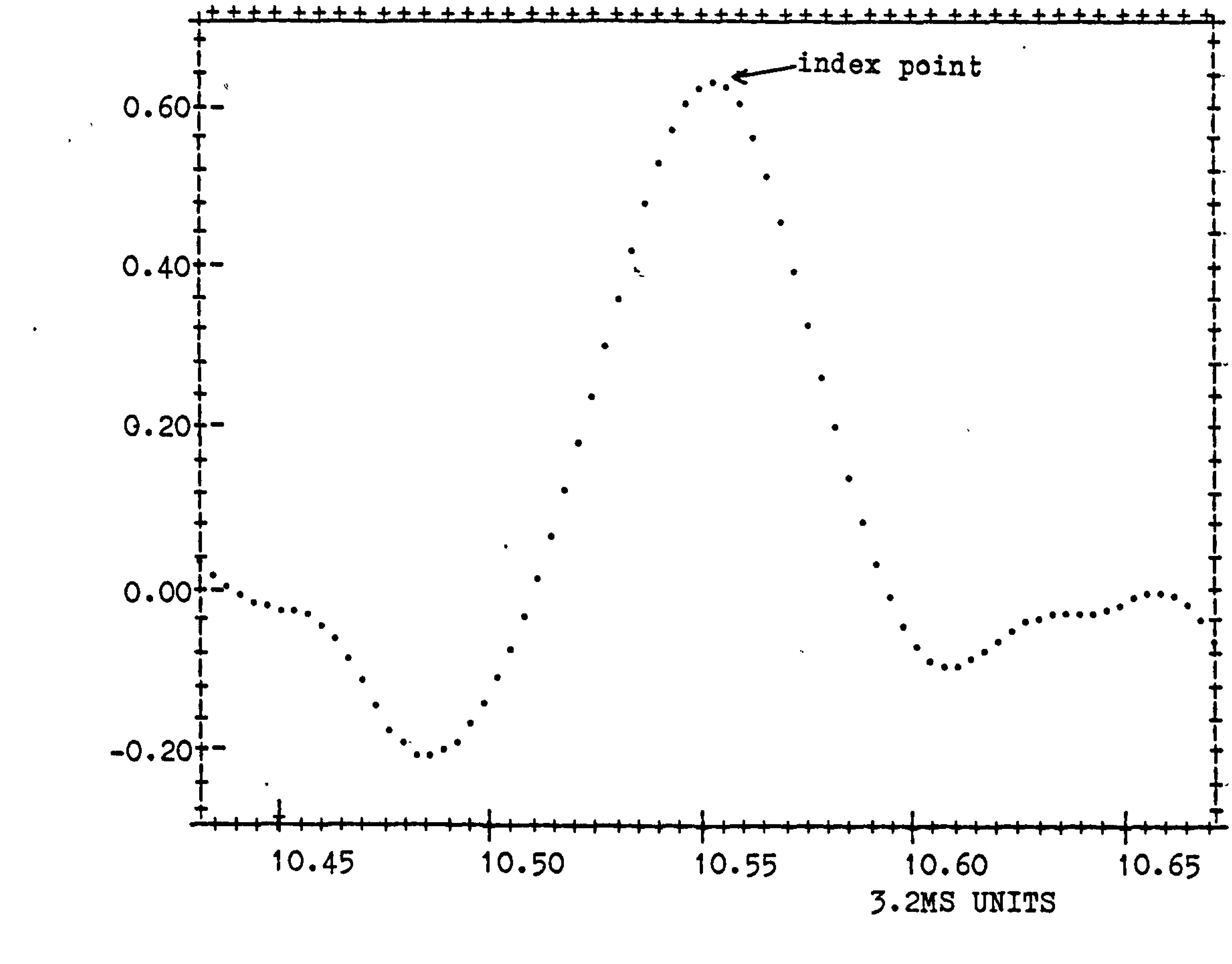


FIGURE 3.5 ABSOLUTE VELOCITY

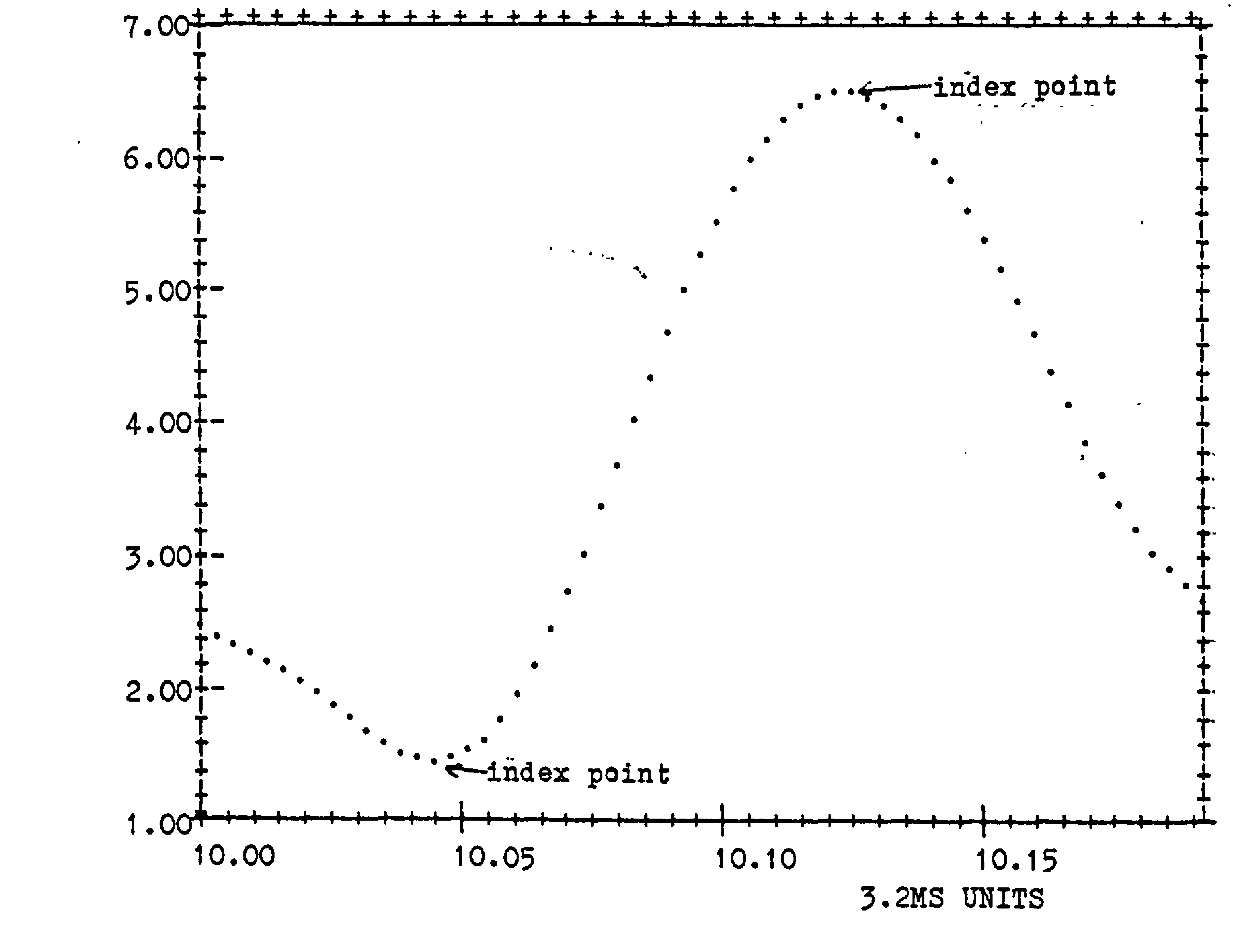
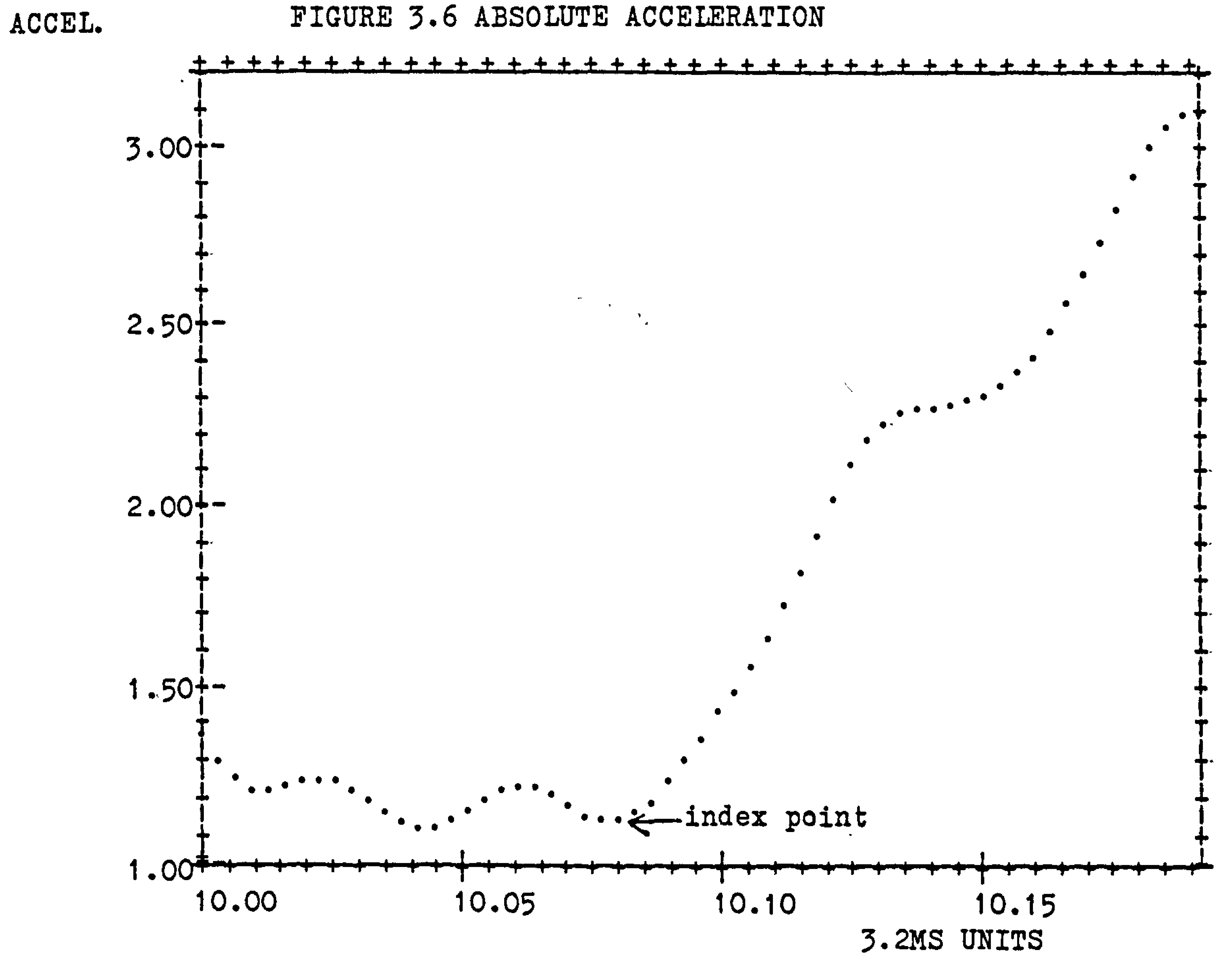
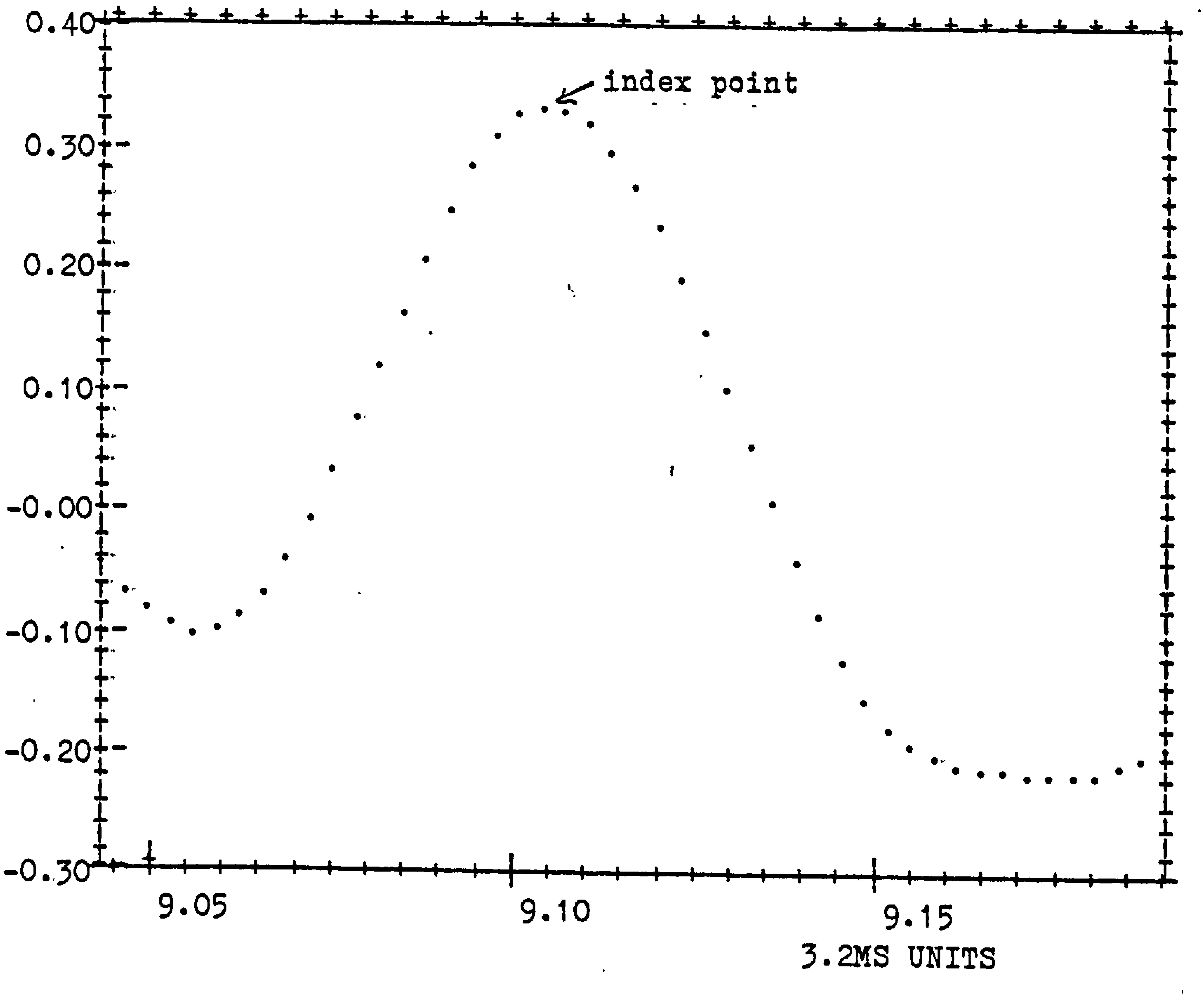


FIGURE 3.6 ABSOLUTE ACCELERATION



R.OF C. FIGURE 3.7 RATE OF CHANGE OF ABS.VEL.



Results

Part one: Selection of Index.

The selection between the indices was made on the basis that the greater the absolute mean discrepancy between the conductor's tap and the index reference point, the less the likelihood that the index point was being used to indicate beat location. Absolute means were used in preference to real means, as it was more important to assess the extent rather than the direction of the error. A small signed mean could conceal a large variance that indicated a non-systematic relationship. The summary data is given in table one.

Table one

Comparison of Indices. Absolute differences of tap times from index reference point times, in ms.

(a) 2:4, second trial, bars one to eight.

Indices	Conductor Mean	Conductor S.D.	Violinist Mean	Violinist S.D.
(a) Y position	10.9	10.9	31.5	23.4
(b) Y velocity	11.4	8.1	28.8	22.4
(c) Y accel.	10.9	9.7	21.0	16.2
(d) Abs.vel (1).	11.9	9.0	29.7	22.5
Abs.vel (2)	51.9	11.1	29.9	20.8
(e) Abs.acc.	54.2	23.8	58.7	32.3
(f) R.of C.of V.	19.4	10.2	17.6	12.6

(b) 3:4, second trial, bars one to eight.

Indices	Conductor Mean	Conductor S.D.	Violinist Mean	Violinist S.D.
(a) Y position	15.4	12.6	32.1	23.9
(b) Y velocity	16.4	10.0	31.7	24.6
(c) Y accel.	27.7	15.2	34.4	29.7
(d) Abs.vel (1).	18.2	22.5	32.9	26.6
Abs.vel (2)	69.8	18.1	67.9	39.8
(e) Abs.acc.	28.1	14.6	35.1	29.4
(f) R.of C.of V.	31.9	16.1	37.6	33.5

The results fall into two groups, those with means between 10 and 11ms, and those with considerably greater means. The second group, comprising absolute velocity (with respect to the peak), rate of change of absolute velocity, absolute acceleration, and the Y component of the acceleration were thus eliminated as cues, leaving only Y component position, Y component velocity, and absolute velocity (with respect to the start of the rise). In both the 2:4 and the 3:4, the only effect of including the X component in the velocity data was to slightly increase both the size of the mean discrepancy and the size of the S.D.'s. This represented no improvement over the Y component of the velocity alone, and it was therefore excluded (by Occam's razor).

There is little difference between the surviving candidates, the Y components of position and velocity. In fact, the transition between negative to positive velocity normally coincided with the positional minima. Those points where it did not could be accounted for by slight ambiguities in the data, and hence in the selection of points in time. For the second stage of the analysis, the Y component of position was selected from these two as the key index of beat location, as this corresponds to musicians' terminology. All beats from every trial are shown in figures 3.8 to 3.11, plotted around this chosen index point. The centre of each graph represents exact coincidence with the reference point for that index. The diagonal line marks the exact synchronisation of the conductor's and the violinist's taps. The distance from the diagonal on either axis gives the difference between the taps of the conductor and the violinist.

Figure 3.08
Soldatenlied, first trial
Each axis represents 150ms

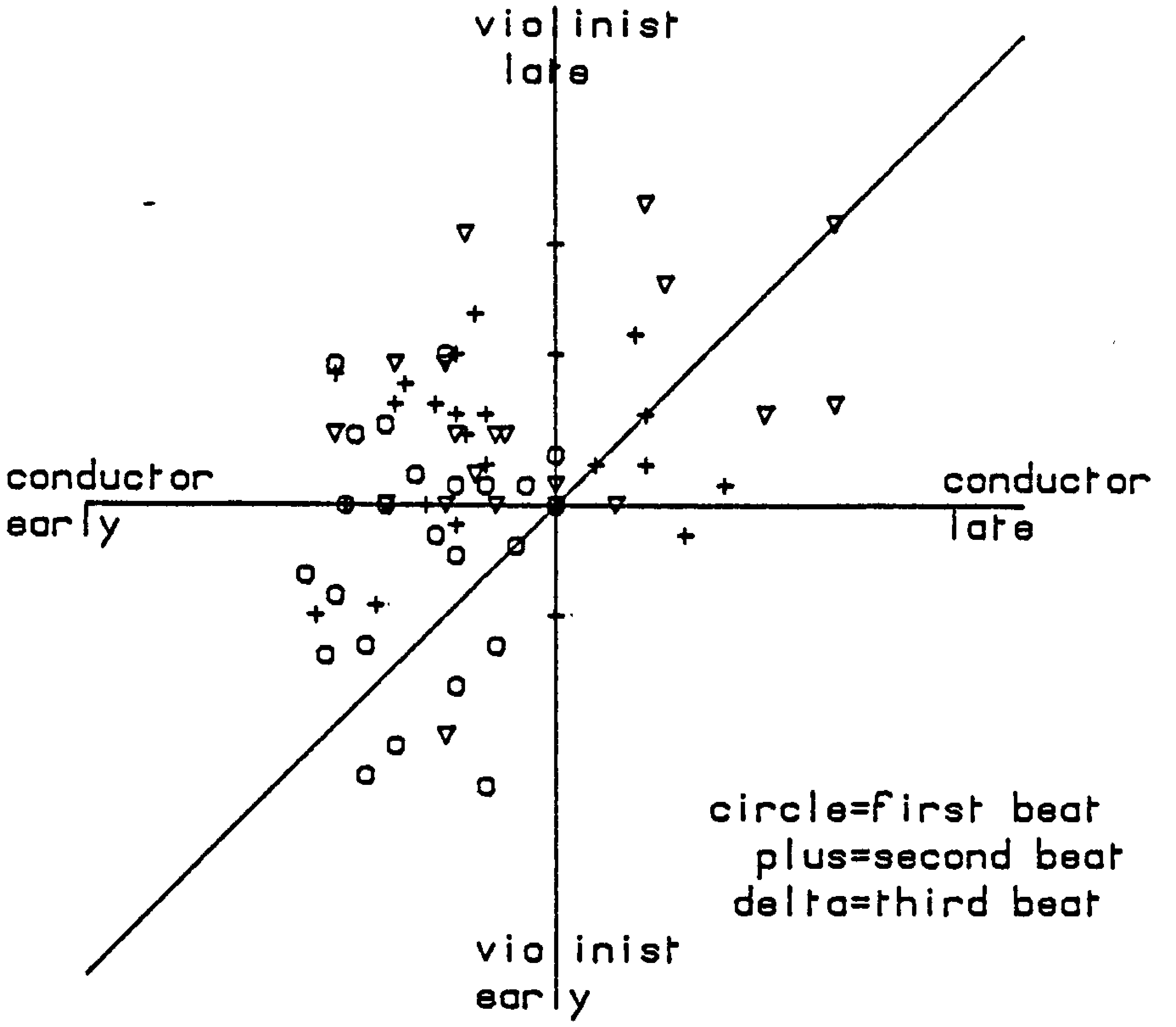


Figure 3.09
Soldatenlied, second trial
Each axis represents 150ms

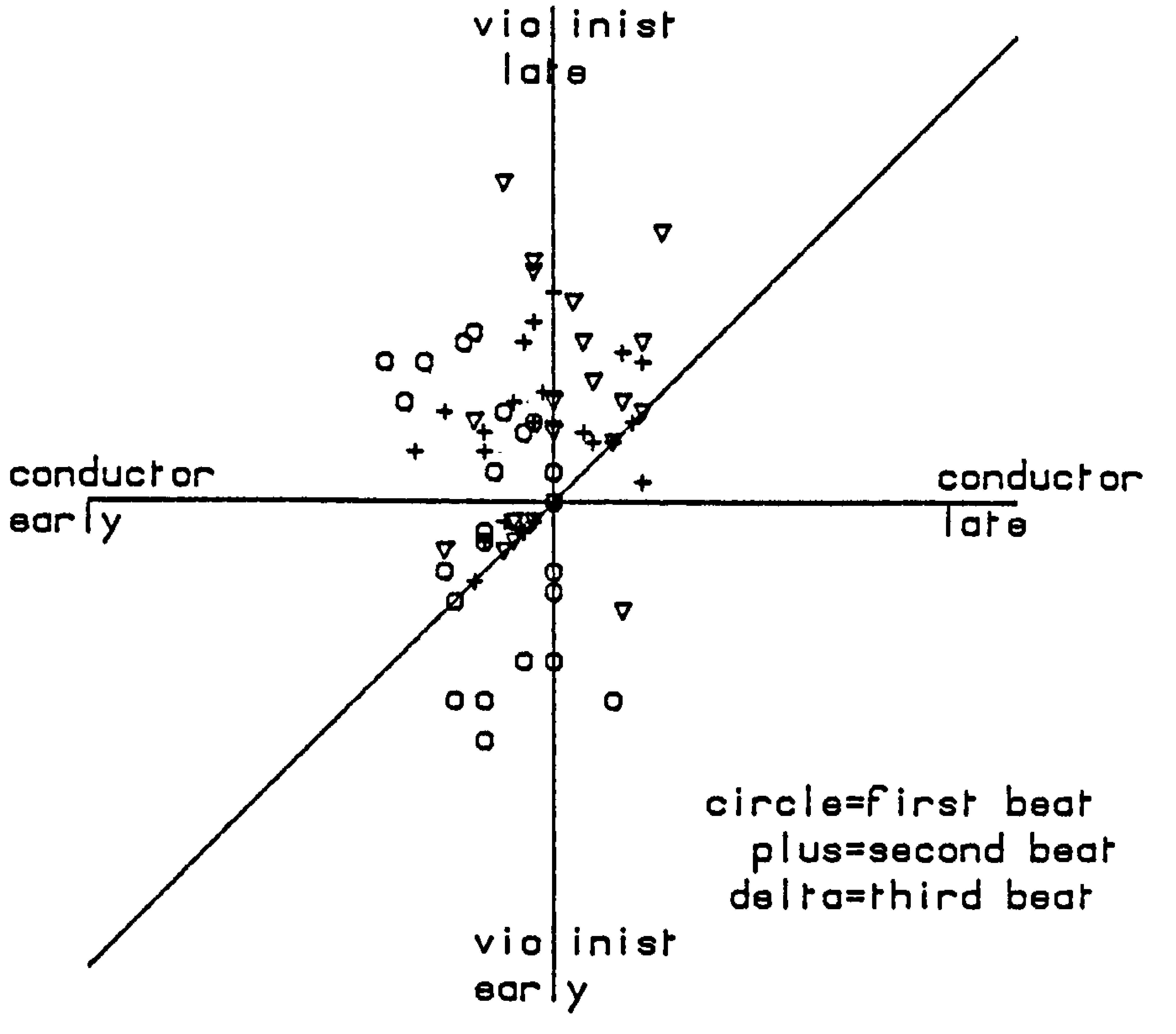


Figure 3.10
Hinke-Tanz, first trial
Each axis represents 150ms

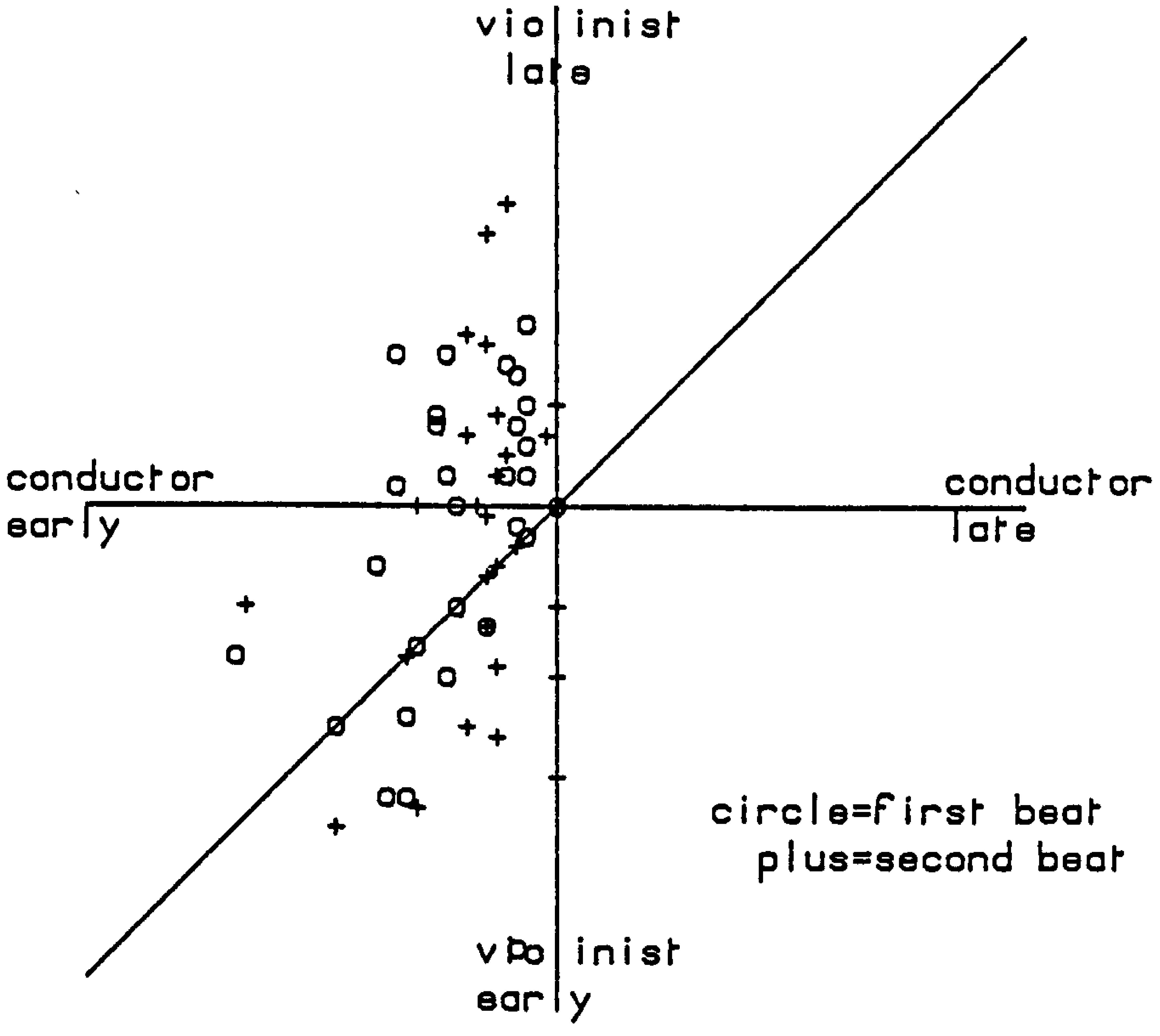
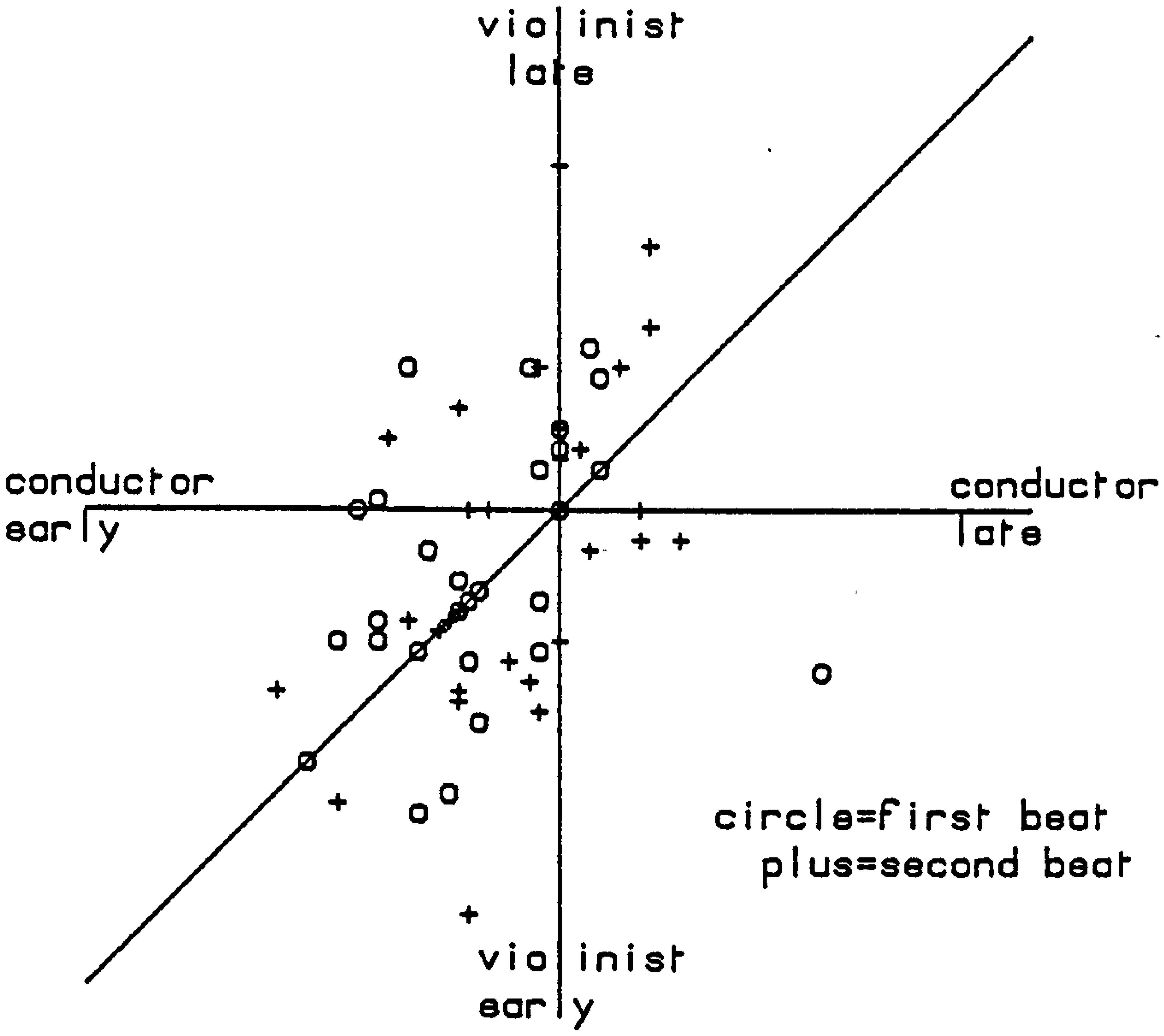


Figure 3.11
Hinke-Tanz, second trial
Each axis represents 150ms



Note that the baton positional minima were often relatively poorly defined, compared with the precision of inter-player event matching. That is, the baton would, at the slow tempo, on occasion plateau on the bottom and remain on a level for 30 or 40ms. Figure 3.12 illustrates this, while figure 3.13 illustrates the punctuate nature of the beat at the fast tempo. Taking the minima to equal the arrival at or departure from the bottom did not affect the profile of results, thus the "minima" always refers to the midpoint of these plateau. This in turn requires the adoption of a definition of the beat in this phase of action compatible with the definition of a perceptual centre developed by Morton et al (1976), and Marcus (1981) to describe that which is regular in a perceptually regular sequence of speech sounds. Marcus suggests that it is not possible to determine a perceptual centre in terms of a single acoustic correlate, or absolutely in time, but that these centres are properties of their environment, the whole stimulus, and reflect properties of both the production and perception of speech. Thus although the minima may appear to be relatively poorly defined in terms of its immediate location, in the context of its larger environment it must be sufficiently well defined to allow the precision observed. This interpretation is supported by Boult's insistence that a jerky movement of the stick aimed at marking the rhythm defeats its own purpose, and that the stick had to be kept swinging, reaching its extreme positions just at the beat. The following is from Boult (1943).

FIGURE 3.12 LARGE GRANDEUR, LARGHETTO

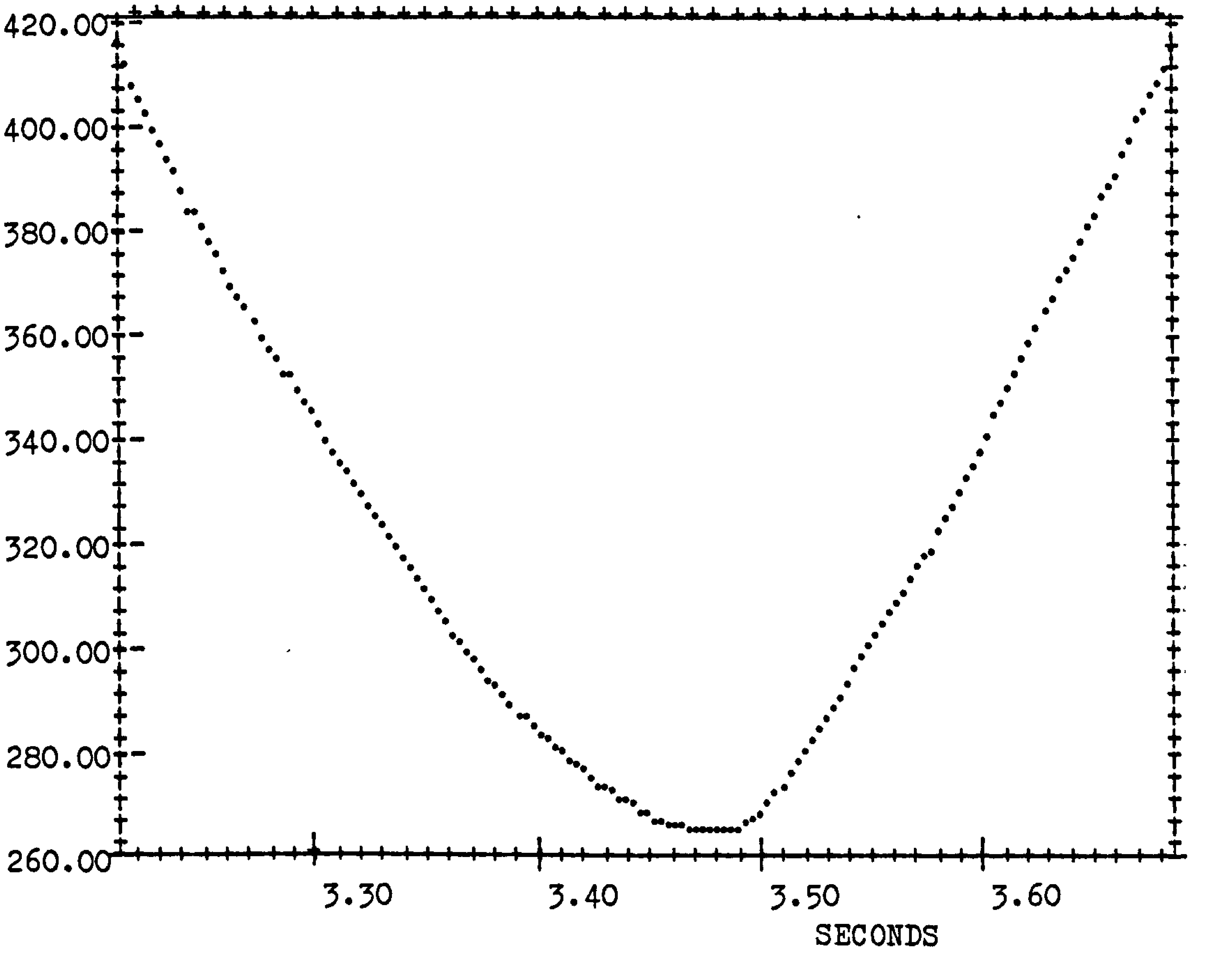
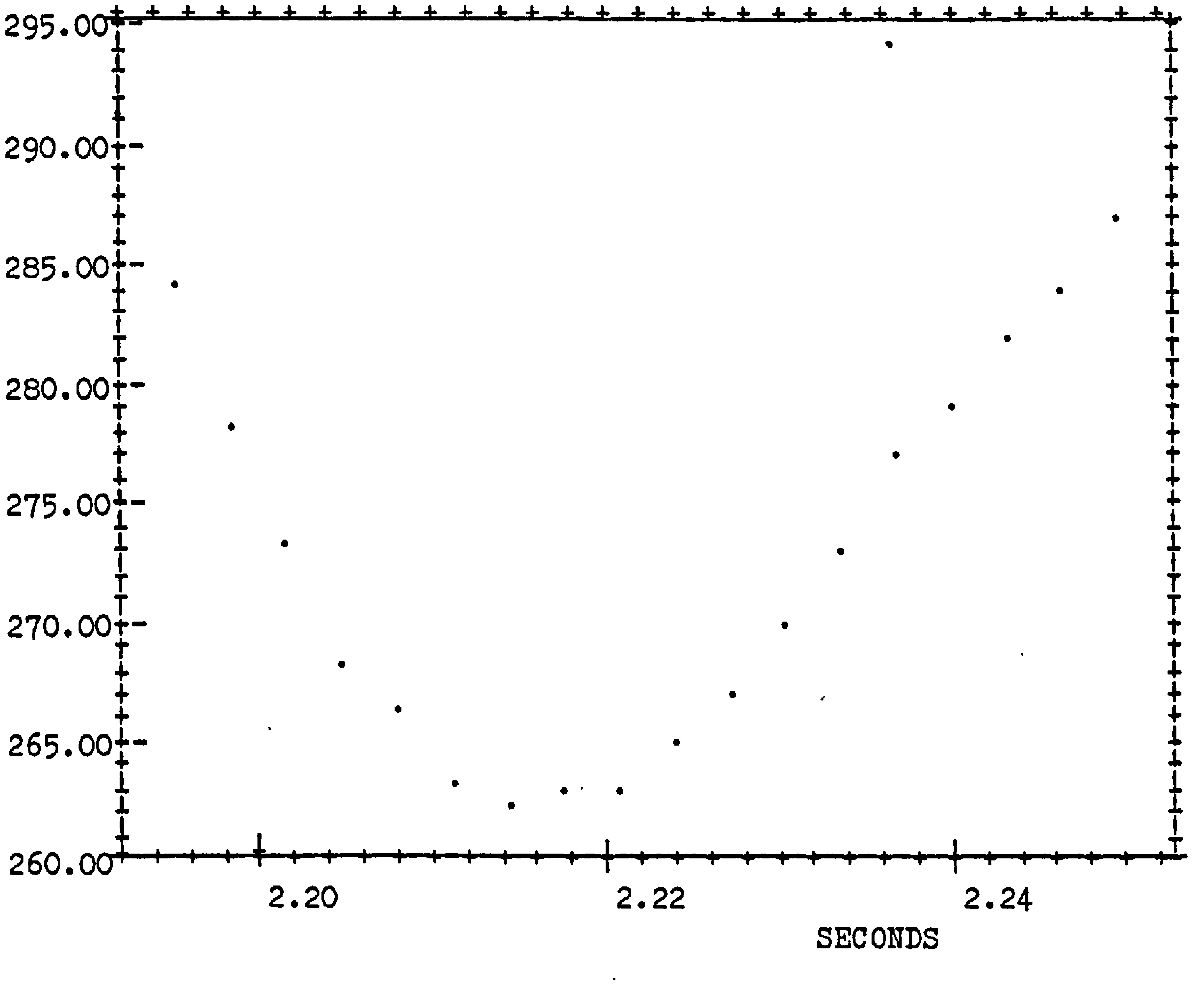


FIGURE 3.13 SMALL GRANDEUR,PRESTO



> "Generally speaking, the movement of the baton is an accelerando from each beat to the next, that is to say, the movement when the baton moves slowest is the moment after it has "clicked" on the beat, and its fastest moment is immediately before the next click."

Thus the emphasis is not on the sharpness with which the beat could be demarcated, but on the regularity of the movement to and from it, which would affect the predictability required. McElheren (1966) also emphasises the need to keep movements as smooth, and therefore as predictable, as possible.

<u>Part two: Playing around the beat.</u>

Having selected the index, inter-beat intervals (IBI) may then be calculated. These IBI's are shown in figures 3.14 and 3.15, for the 3:4 and the 2:4 respectively. While the exact tempo is not repeated between trials, the pattern of time allocation over the bar is robust and replicated. Thus in both the 3:4 and the 2:4 music, the longest duration was given to the interval before the first beat of each bar. In both cases the interval between the first and second beats was the shortest in the bar. The simplest explanation of this pattern is that the first beat of the bar is displaced forwards in time with respect to where it would be if the IBI's had been of equal duration. The first beat of the bar is generally reported to be particularly important for synchronising actions. This was confirmed by the subjects to be true in this instance. The temporal displacement would allow an amplified signal of those actions that indicated the prospective arrival of that beat. This may be the purpose of that displacement.

When the tempo is changed the IBI's alter accordingly. The patterning over the bar, however, is maintained, in that the largest duration is still given to the interval before the first beat. However, the actual difference between the longest and shortest intervals is approximately the same before and after the tempo change. This means that the difference is translated absolutely, not proportionately. Kelso et al (1981) argue that a given muscle synergy may be designed around particular requirements or environmental demands, then driven at different rates. The differences in the timing of movement components should thus be scalar over changes in rates, within certain bounds. Therefore, if Kelso is correct, this means that the changes in tempi straddle synergy boundaries, and that during both directions of tempo change there must be a reorganisation of the structure of the movement.

When all the tap times are compared with the positional minima, further dynamic patterning emerges. The taps do not occur synchronously with the baton beat, but in a certain relationship to it. The summary data (the index point times with the tap times subtracted)) are given in table two. The means and S.D.'s are plotted in figures 3.16, 3.17, 3.18, and 3.19, for first and second attempts on the 2:4 and on the 3:4 respectively.

Figure 3.14
Inter beat intervals
between baton Y-axis minima .

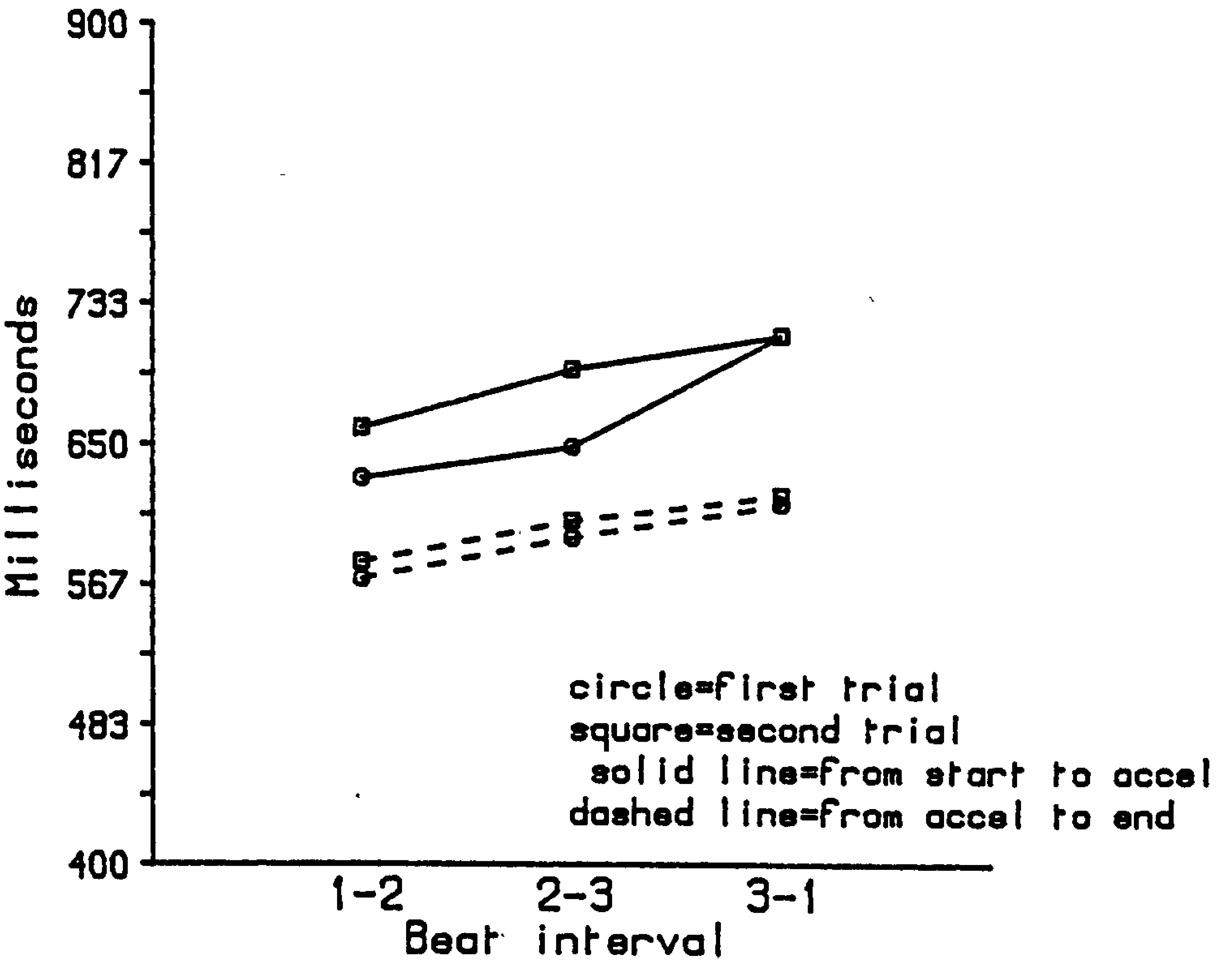


Figure 3.15
Inter beat intervals
between baton Y-axis minima

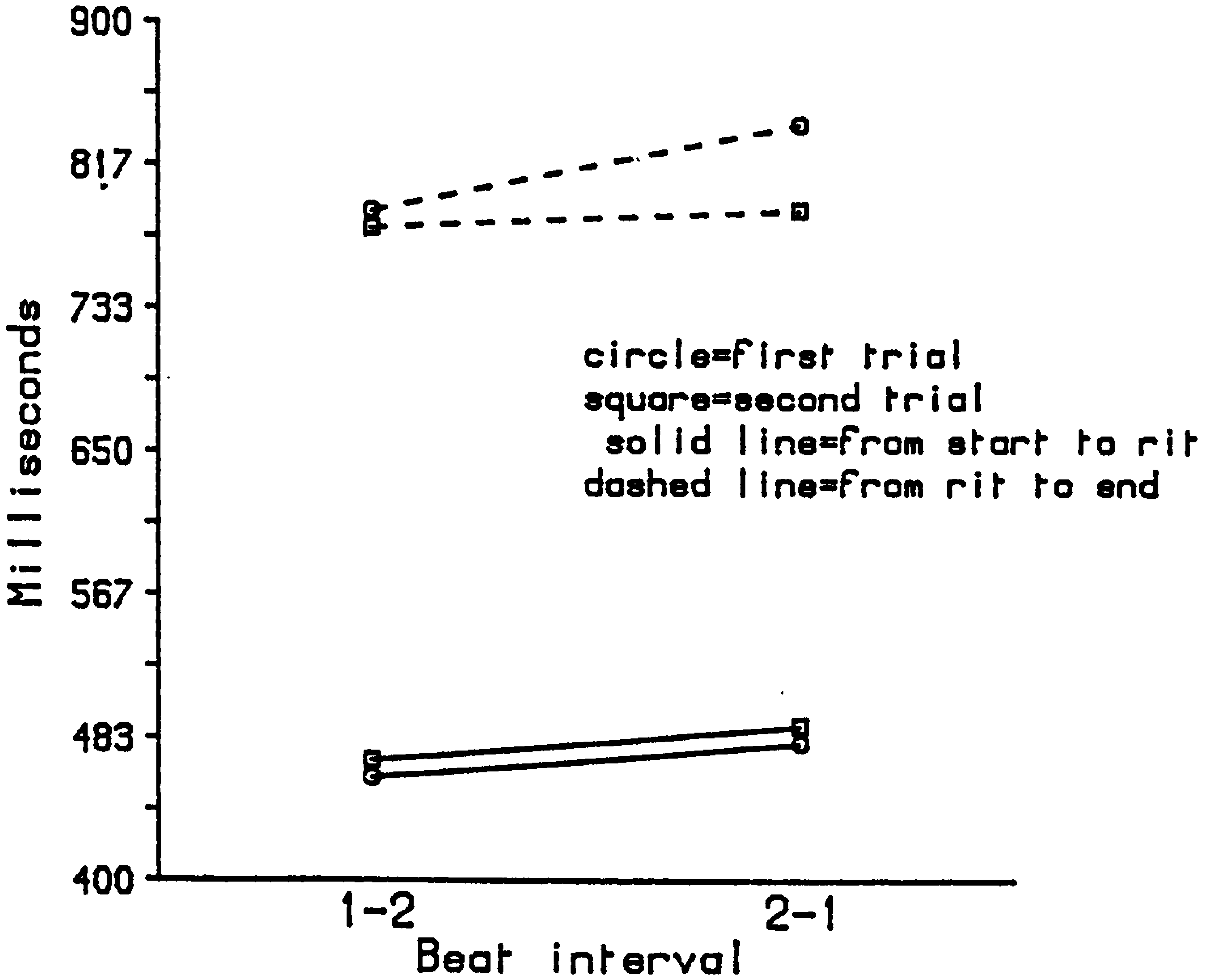


Figure 3.16
Means and S.D.'s of differences between tap times and baton beats Hinke-Tanz, first trial

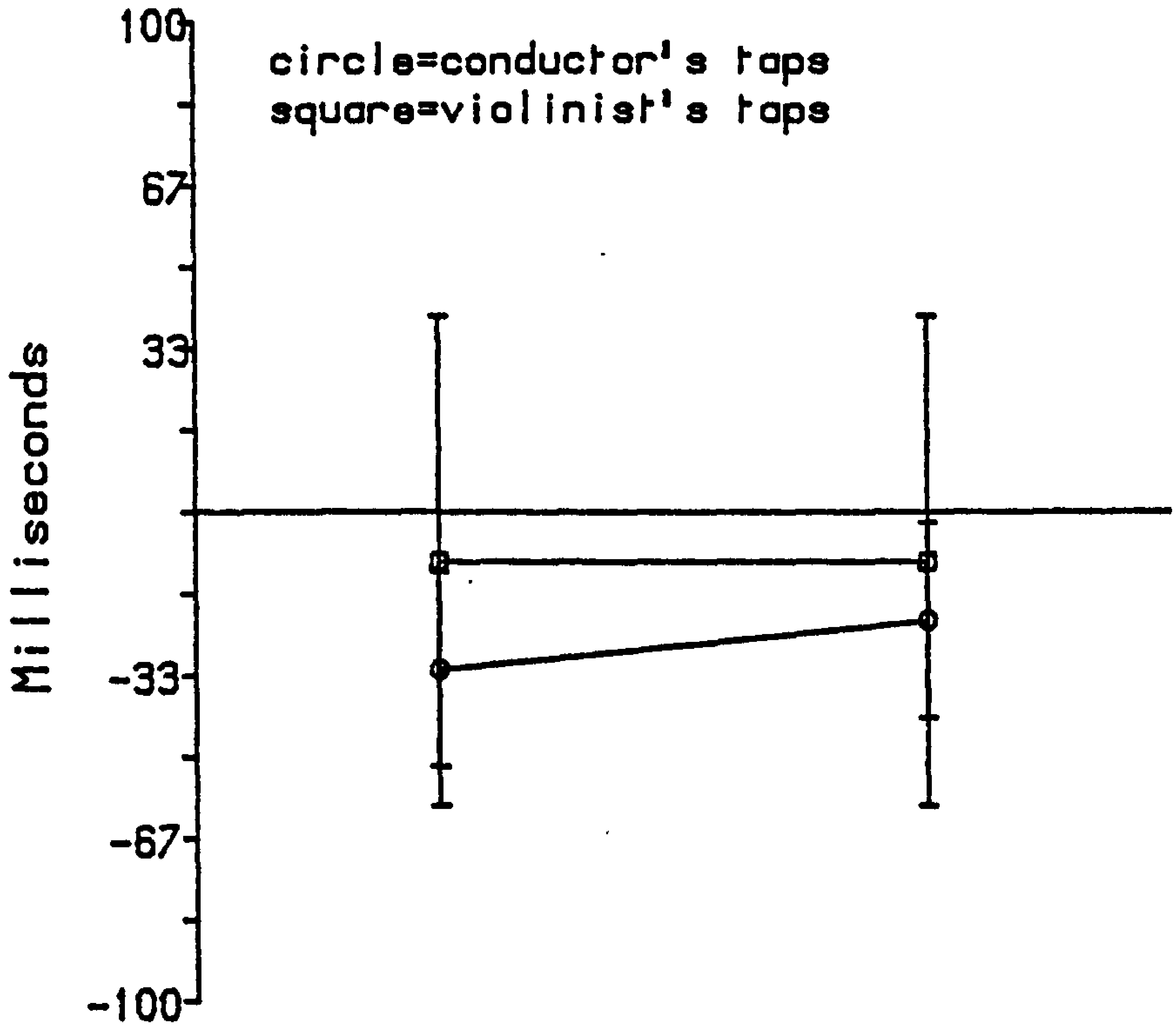


Figure 3.17
Means and S.D.'s of differences between tap times and baton beats
Hinke-Tanz, second trial

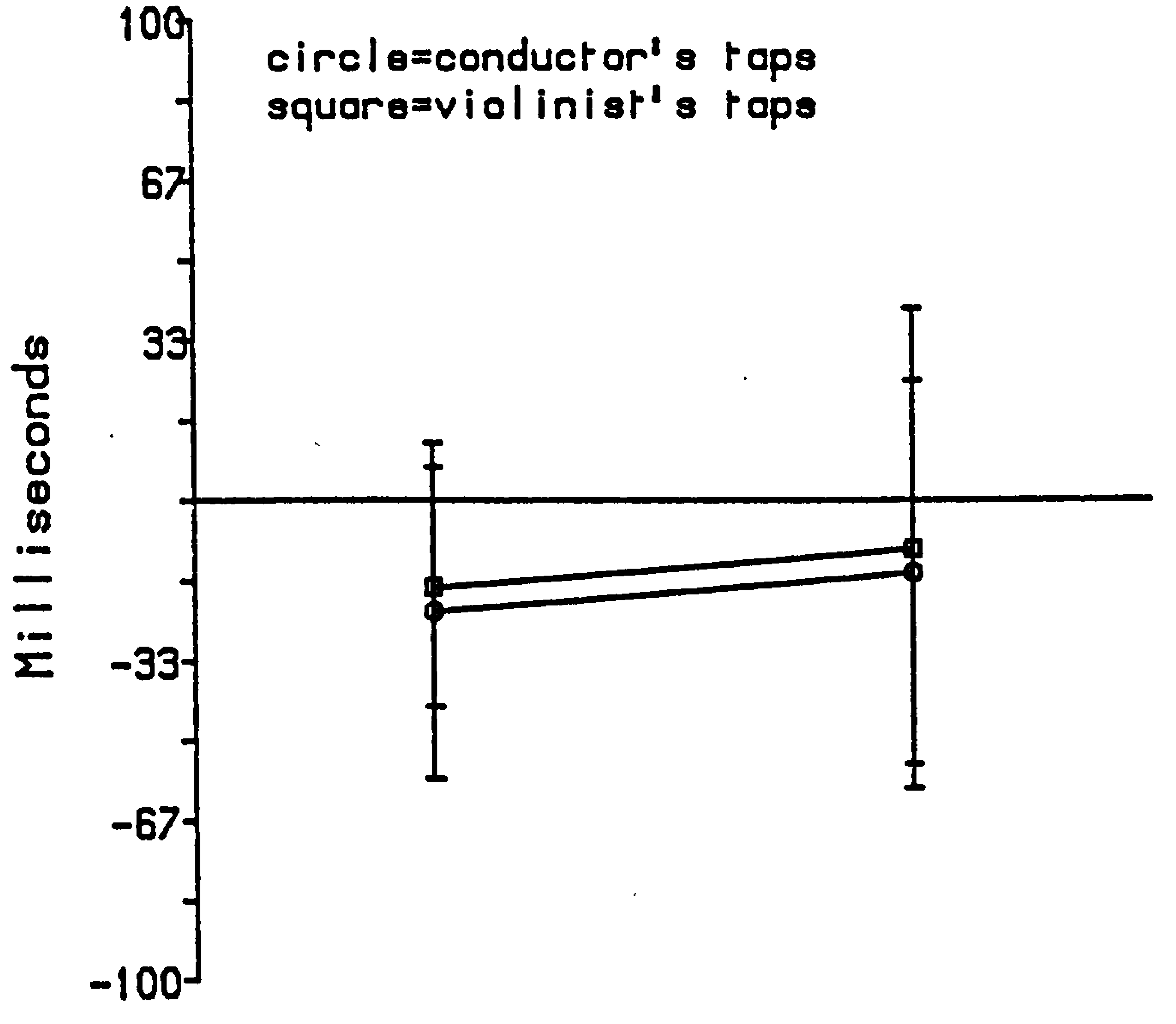


Figure 3.18
Means and S.D.'s of differences
between tap times and baton beats
Soldatenlied, first trial

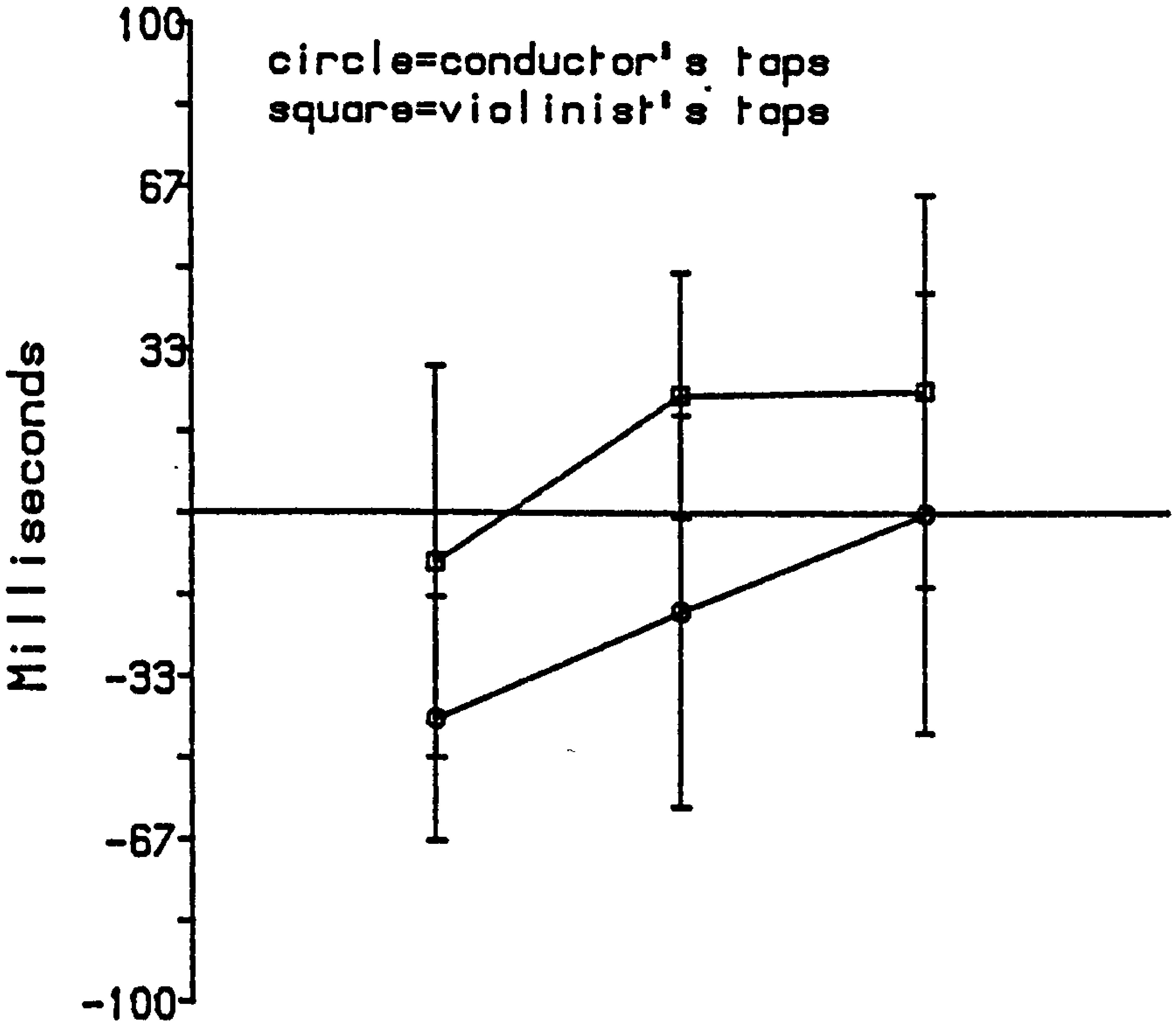


Figure 3.19
Means and S.D.'s of differences between tap times and baton beats Soldatenlied, second trial

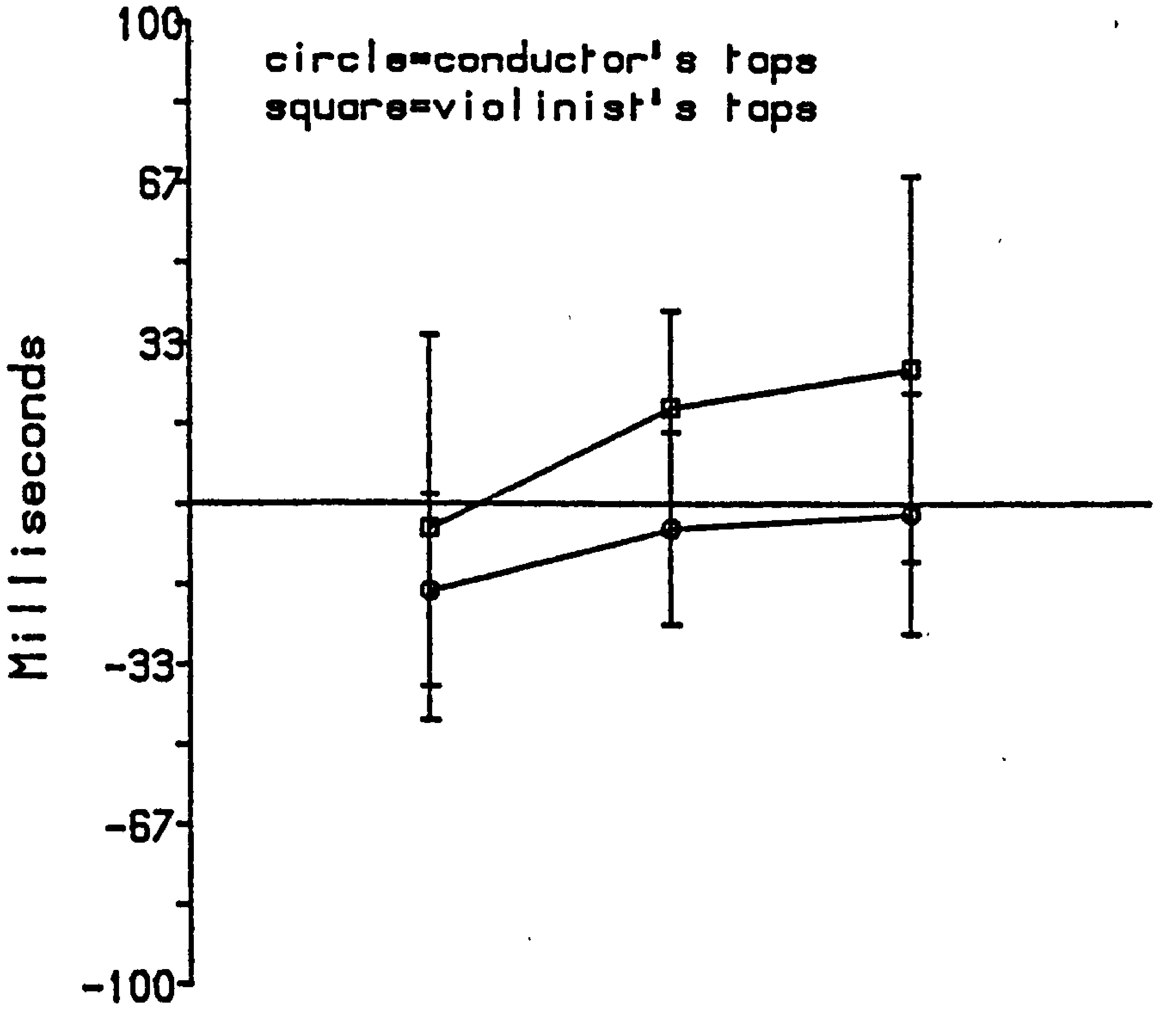


Table two

Index-tap differences, in ms. When a mean is negative, the tap occurred first.

(a) 2:4, first trial, conductor.

	Beat one	Beat two	All beats
N =	30	30	60
Mean =	-32.0	-22.5	-27.3
S.D. =	22.5	22.1	22.6

(b) 2:4, first trial, violinist.

	Beat one	Beat two	All beats
N =	29	30	59
Mean =	-10.7	-11.8	-11.3
S.D. =	49.6	49.9	49.4

(c) 2:4, second trial, conductor

	Beat one	Beat two	All beats
N =	30	30	60
Mean =	-22.8	-13.3	-18.1
S.D. =	33.0	30.7	31.9

(d) 2:4, second trial, violinist.

	Beat one	Beat two	All beats
N =	30	30	60
Mean =	-17.8	-10.8	-14.3
S.D. =	39.8	51.6	45.8

(e) 3:4, first trial, conductor.

	Beat one	Beat two	Beat three	All beats
N =	22	22	21	65
Mean =	-42.0	-20.9	-2.1	-22.0
S.D. =	25.5	35.1	46.4	-39.4

(f) 3:4, first trial, violinist.

	Beat one	Beat two	Beat three	All beats
N =	21	21	20	62
Mean =	-11.6	23.2	26.2	12.4
S.D. =	36.9	29.1	39.3	38.8

(g) 3:4, second trial, conductor

	Beat one	Beat two	Beat three	All beats
N =	22	22	22	66
Mean =	-17.2	-3.6	-1.9	-7.6
S.D. =	18.5	19.5	26.4	22.9

(h) 3:4, second trial, violinist.

	Beat one	Beat two	Beat three	All beats
N =	22	21	21	64
Mean =	-5.7	21.2	29.1	14.6
S.D. =	37.6	21.5	36.9	36.5

Figures 3.16 to 3.19 reveal how, in every case, the conductor taps before his baton reaches the bottom. This is most marked on the first beat in each bar, where the minima is displaced forewards in

time, but his foot-tap is not. In the 2:4 trials, the foot-tap occurs approximately where the baton minima should occur if there was an even division of the time. In the 3:4 piece, the discrepancy between the conductor's tap and his baton minima on the first beat in the bar is not as great as the discrepancy between the IBI between the third and first beats and the IBI between the first and second beats. This is not, therefore, a simple displacement. However, the outstanding discrepancy may be accounted for by an allocation of the temporal irregularities between the interval between beats two and three and the interval between beats three and one.

Thus the conductor taps a more regular interval with his foot than he indicates with his baton. This indicates that the baton action is based on a regular interval around the bar length, but is temporally patterned. The means and S.D.'s of tap locations, and the means and S.D.'s of baton beat locations, are given in table three. The IBI's are shown in figures 3.14 and 3.15, the inter-tap-intervals (ITI's) are shown in figures 3.20 and 3.21, and 3.22 and 3.23, for the 3:4 and the 2:4 for the conductor and violinist respectively.

T-tests with the 2:4 trials, and ANOVA with the 3:4 trials reveal that the inter-tap-intervals are generally not significantly different from each other. This is so both for the conductor and the violinist. They are, therefore, tapping essentially equal intervals. There is one exception, the violinist's taps in the second trial at

Figure 3.20
The conductor's
inter tap intervals

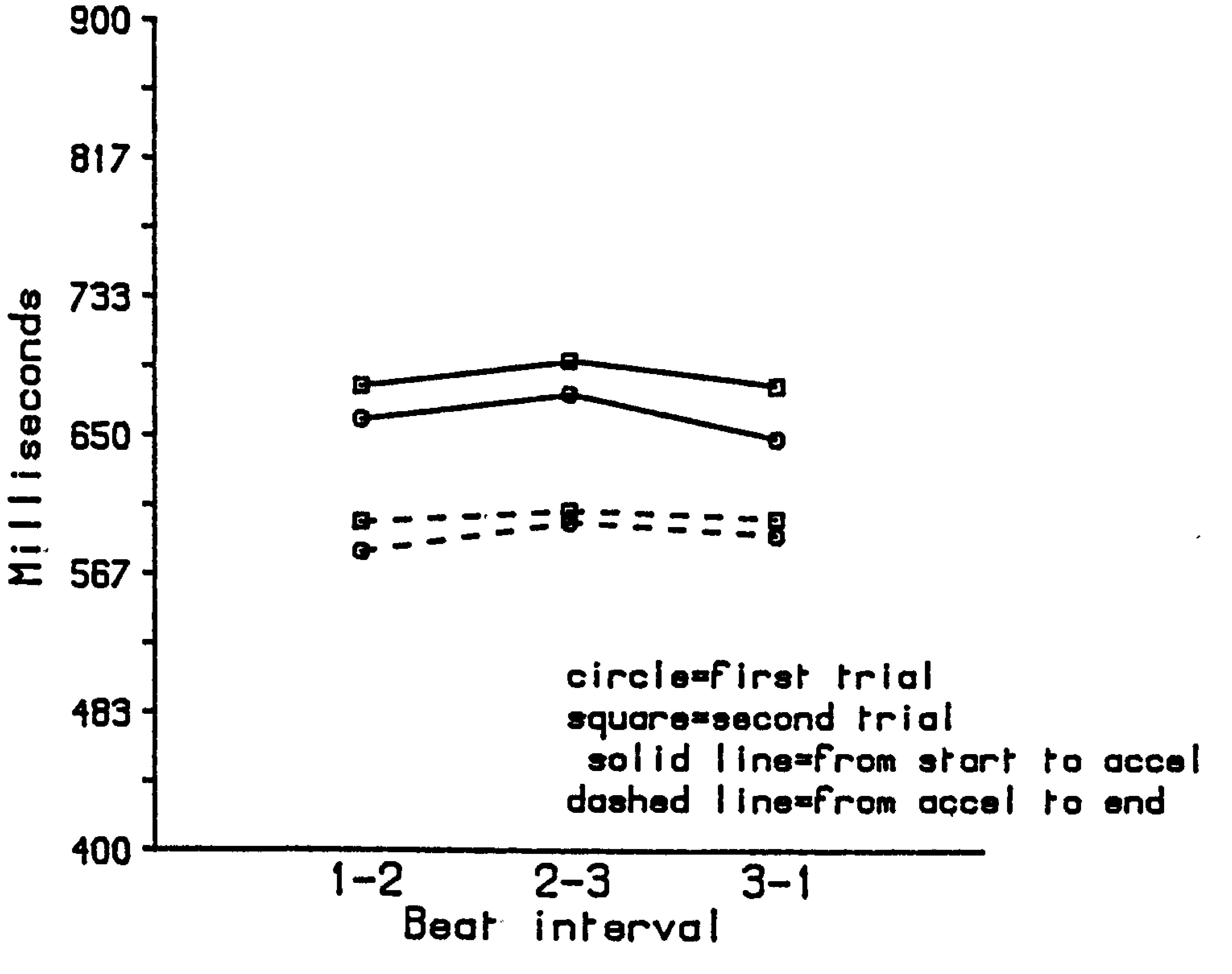


Figure 3.21
The conductor's
inter tap intervals

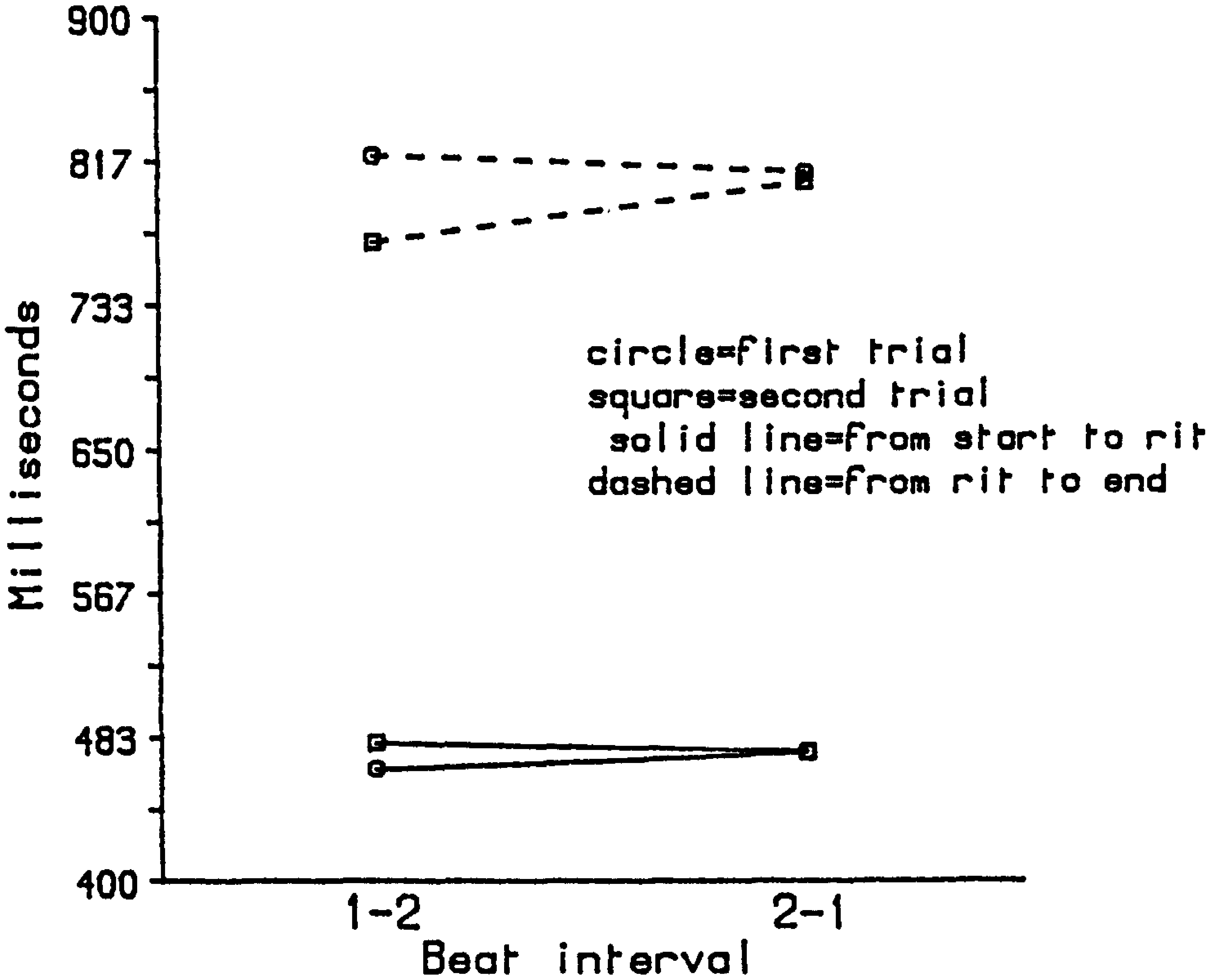


Figure 3.22
The violinist's
inter tap intervals

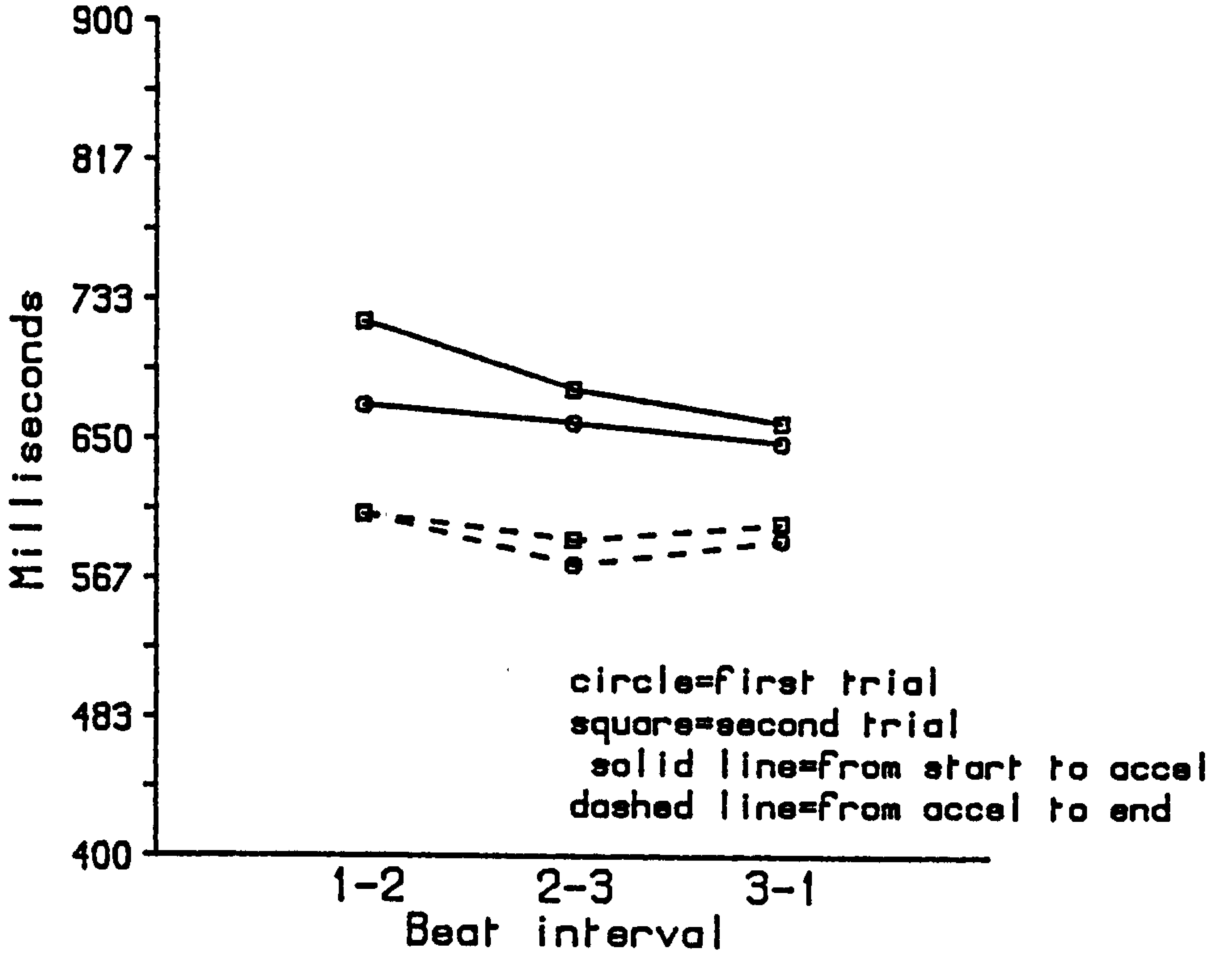
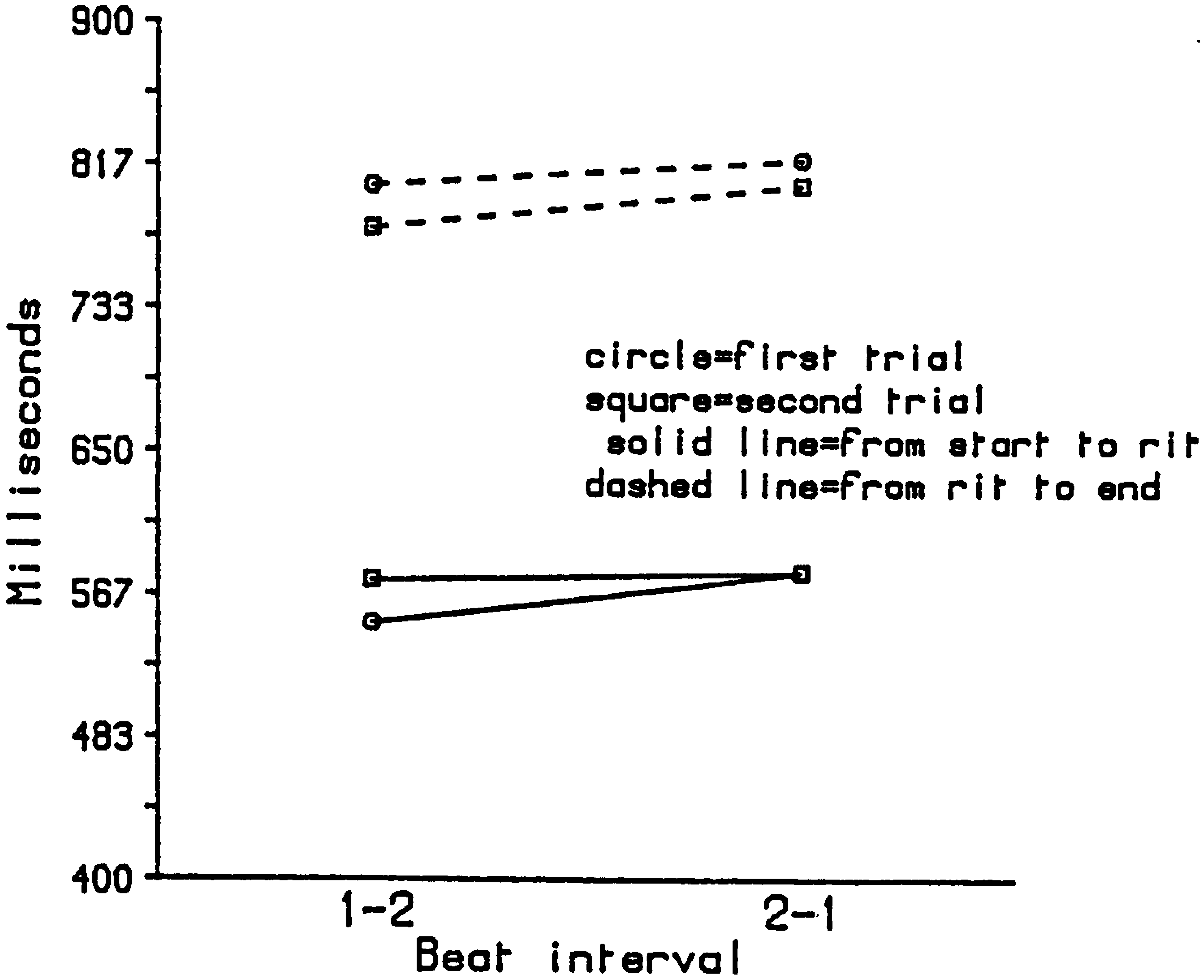


Figure 3.23
The violinist's
inter tap intervals



the 3:4 piece over the first seven bars to the accelerando are patterned, but she reverts to approximately equal intervals after the accelerando. The inter-beat-intervals of the conductor's baton, however, are markedly different from each other. In only two cases did the patterning fail to be significant, of those, only one fell far short (the last six bars of the second trial at the 2:4).

Table three

IBI's and ITI's.

(a) 2:4, first trial, beginning to ritardando.

	From 1-2	From 2-1	All intervals	Sig level
Baton				
N =	21	20	41	0.01
Mean =	456.9	478.1	467.2	
S.D. =	27.6	22.7	27.2	
Conductor's taps				
N =	20	20	40	not sig
Mean =	463.0	476.1	468.6	
S.D. =	28.2	23.6	26.3	
Violinist's taps				
N =	18	19	37	not sig
Mean	452.6	484.6	469.0	
S.D. =	44.5	38.1	43.8	

(b) 2:4, first trial, ritardando to end

	From 1-2	From 2-1	All intervals	Sig level
Baton				
N =	6	5	11	0.1
Mean =	789.3	838.4	813.6	
S.D. =	43.7	36.2	46.2	
Conductor's taps				
N =	6	6	12	not sig
Mean =	822.4	808.0	815.2	
S.D. =	49.2	42.7	44.6	
Violinist's taps				
N =	6	6	12	not sig
Mean =	804.5	822.4	813.6	
S.D. =	55.9	24.3	42.1	

(c) 2:4, second trial, beginning to ritardando.

	From 1-2	From 2-1	All intervals	Sig level
Baton				
N =	21	20	41	0.01
Mean =	464.4	490.4	477.1	
S.D. =	18.0	13.8	20.6	
Conductor's taps				
N =	20	20	40	not sig
Mean =	483.4	472.1	477.7	
S.D. =	18.1	25.0	22.3	
Violinist's taps				
N =	20	20	40	not sig
Mean	466.6	487.0	476.8	
S.D. =	38.4	48.1	44.2	

(d) 2:4, second trial, ritardando to end

	From 1-2	From 2-1	All intervals	Sig level
Baton				
N =	6	5	11	not sig
Mean =	779.7	796.4	787.3	
S.D. =	45.6	39.2	41.6	
Conductor's taps				
N =	6	6	12	not sig
Mean =	774.3	804.5	789.4	
S.D. =	95.3	33.2	69.8	
Violinist's taps				
N =	6	6	12	not sig
Mean =	782.3	805.6	793.9	
S.D. =	37.9	70.3	55.2	

(e) 3:4, first trial, beginning to accelerando.

	From 1-2	From 2-3	From 3-1	All intervals	Sig level
Baton					
N =	7	7	7	21	0.01
Mean =	627.7	642.7	714.4	661.6	
S.D. =	33.9	28.6	48.2	52.8	
Conductor's taps					
N =	7	7	6	20	not sig
Mean =	656.5	674.7	649.0	660.6	
S.D. =	32.4	14.6	11.7	23.6	
Violinist's taps					
N =	7	6	5	18	not sig
Mean	670.2	665.1	648.2	661.4	
S.D. =	34.0	36.2	19.5	31.2	

(f) 3:4, first trial, accelerando to end

	From 1-2	From 2-3	From 3-1	All intervals	Sig level
Baton					
N =	12	12	11	35	not sig
Mean =	572.8	590.6	608.9	590.3	
S.D. =	43.9	35.6	19.4	36.9	
Conductor's taps					
N =	12	14	11	37	not sig
Mean =	580.2	597.6	588.9	589.4	
S.D. =	46.9	24.4	34.9	35.8	
Violinist's taps					
N =	11	10	8	29	not sig
Mean =	605.7	574.3	590.5	589.2	
S.D. =	43.5	53.6	28.4	43.7	

(g) 3:4, second trial, beginning to accelerando.

	From 1-2	From 2-3	From 3-1	All intervals	Sig level
Baton					
N =	7	7	7	21	0.01
Mean =	668.4	693.1	705.1	688.9	
S.D. =	19.8	24.1	30.9	28.7	
Conductor's taps					
N =	7	7	6	20	not sig
Mean =	684.4	690.9	682.8	686.2	
S.D. =	17.9	21.1	14.5	17.6	
Violinist's taps					
N =	7	7	6	20	0.01
Mean	721.5	686.3	658.8	690.4	
S.D. =	28.0	25.9	31.2	37.3	

(g) 3:4, second trial, accelerando to end

	From 1-2	From 2-3	From 3-1	All intervals	Sig level
Baton					
N =	12	12	11	35	0.05
Mean =	583.5	604.6	621.0	602.5	
S.D. =	22.4	42.3	16.7	32.6	
Conductor's taps					
N =	12	12	9	33	not sig
Mean =	598.4	608.9	595.9	601.5	
S.D. =	21.2	27.6	13.3	22.2	
Violinist's taps					
N =	11	10	9	30	not sig
Mean =	596.7	605.5	591.6	598.1	
S.D. =	43.7	30.6	34.2	36.1	

The averages of the ITI's and the IBI's are very similar. This is not in itself surprising, as if they were not, the players would be progressively diverging. What makes this interesting is that within the bars there are dissimilarities in the allocation of times between the beats. The conductor's foot taps match his baton beats only at the first attempt at the 2:4, in the section before the ritardando. The violinist's foot taps match the conductor's baton beat very well in the 2:4 trials, but generally she reverses the temporal allocations of the first and third beats in the 3:4 trials. This indicates that there is a certain elasticity as to beat durations within the bar.

This conclusion is further supported by the finding that the violinist's tap lagged behind the conductor's in every case, by an average of 25.8ms on first attempts. The lag size tends to remain approximately constant within trials. This reduces to an average lag of 12.2ms on second attempts. This reduction, which is to only 3.8ms in the 2:4 case, must be a practice effect. As the musician becomes more familiar with the framework of movement employed by the conductor, so increasingly accurate prediction of the termini of movement phases becomes possible. The lags are given in table four.

Table four

Differences between tap times. Conductor-violinist. When a mean is negative, the conductor tapped first.

(a) 2:4, first trial.

Difference on -	Beat one	Beat two	All beats
N =	29	30	59
Mean =	-21.3	-11.7	-16.4
S.D. =	46.3	49.4	47.7

(b) 2:4, second trial.

Difference on -	Beat one	Beat two	All beats
N =	30	30	60
Mean =	-5.0	-2.6	-3.8
S.D. =	42.7	44.3	43.1

(c) 3:4, first trial.

Difference on -	Beat one	Beat two	Beat three	All beats
N =	21	21	20	62
Mean =	-29.9	-44.3	-30.9	-35.1
S.D. =	41.9	38.5	47.5	42.5

(d) 3:4, second trial.

Difference on -	Beat one	Beat two	Beat three	All beats
N =	22	21	21	64
Mean =	-11.5	-23.5	-26.8	-20.5
S.D. =	48.0	24.4	38.1	38.2

As the conductor taps a regular beat and indicates a patterned beat with his baton, we may now ask whether the violinist follows the conductor's taps, or his baton? If it is the former, then the violinist must either derive the underlying regularity from the information available to her, the patterned baton wave, or simply tap at regular intervals which match the average IBI. If it is the latter, then she must see the beat where the conductor indicates it to be and adopt the pattern of output in a relatively direct way.

The relevant data is in tables two and four. On the first beat in the bar, in every condition, the violinist's tap falls, on average, between the conductor's tap and the conductor's baton beat. On the second beats in the 2:4 the same happens. With the 3:4, the conductor's tap remains ahead of the baton, the violinist's tap now occurs after the baton beat. On the third beats in the 3:4 the same happens, conductor's taps first, then the baton minima, then the violinist's tap. This may be seen in figures 3.16 to 3.19. The significance levels in table three reveal that neither violinist nor conductor can be said to be tapping a more regular interval than the other. Thus these differences cannot be attributed to undue deviations on the part of either.

What happens on the first beats is most revealing. This result suggests that the relative lateness of the first beat in the baton wave is causing the violinist to over-anticipate, but to a lesser extent than the conductor indicates. That means that there must be both a time at which the violinist expects to play, revealed by her foot-tapping rhythm, and an ability to respond to the patterning indicated by the conductor.

Part 3: Keeping it together

How do the players stay in time, if there is this flexibility in output? The answer is that there is a critical feature around which this flexibility occurs, which, while not remaining constant over time, remains constant between the players from moment to moment. This is the bar length.

Figures 3.24 and 3.25 (first and second attempts on the 3:4) and 3.26 and 3.27 (first and second attempts on the 2:4) show the very high degree of match of the bar lengths of all three recorded variables, both foot-tap switches and the conductor's baton. Notice that even when the tempo is changing the bar lengths remain tightly coupled.

Thus the conclusion is that there is flexibility within the bar, while the bar length plays the role of coordinative structure. The bar length varies considerably throughout each piece, thus this is a dynamic process of bar-length matching.

The situation is therefore analogous to the model developed by

Fowler (1977) for speech production. She compared the perceptual centres of phrases to loci of compression, separated by phases of relative rarefaction, in a spring which was fixed at points, and which could be expanded or contracted in whole or in part. It is perhaps more correct in this case to think of a spring, connected at points to an elastic band. The fixed points are the bar lengths. The conductor controls the rate of expansion (ritardando) or contraction (accelerando) by stretching the elastic band. Thus the absolute distance between the fixed points may be altered. Between the fixed points there is some flexibility as to where the foci of compression (beats in the bar) are to be located. The violinist may locate hers slightly differently from the conductor. The fixed points, however, delineate one zone of flexibility from the next. This ensures overall coordination, even though there might not be an actual point on which the musicians play in unison. This model can be used to explain rubato. Rubato means 'to rob' time from one note or phrase to give it to another. It is thus a deviation from the timing specified in the score. Romantic music generally requires some rubato. The aim of rubato is to give a living feel to the music, while maintaining the underlying beat.

Figure 3.24
Bar lengths
Baton beats and taps
Soldatenlied, first trial

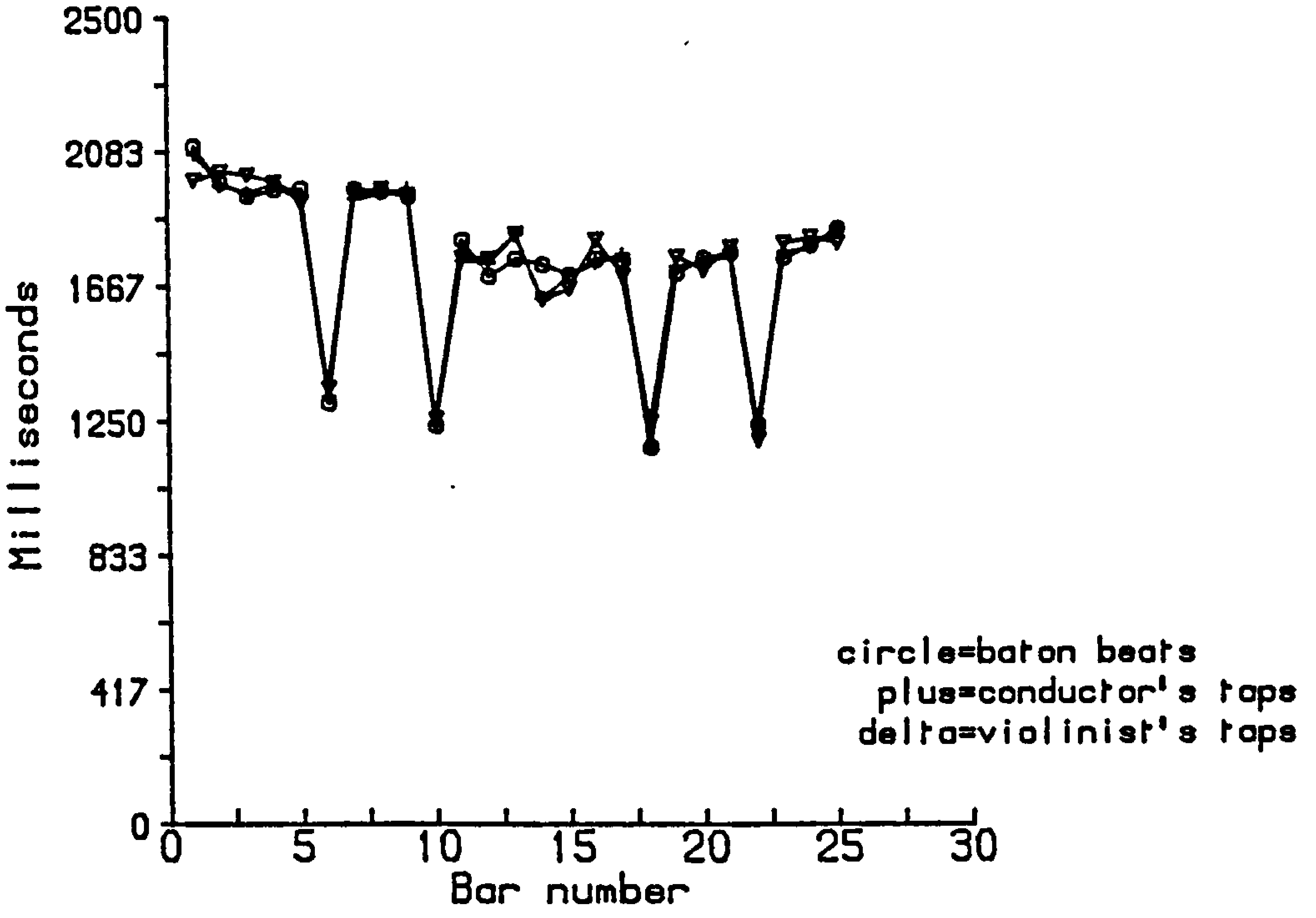


Figure 3.25
Bar lengths
Baton beats and taps
Soldatenlied, second trial

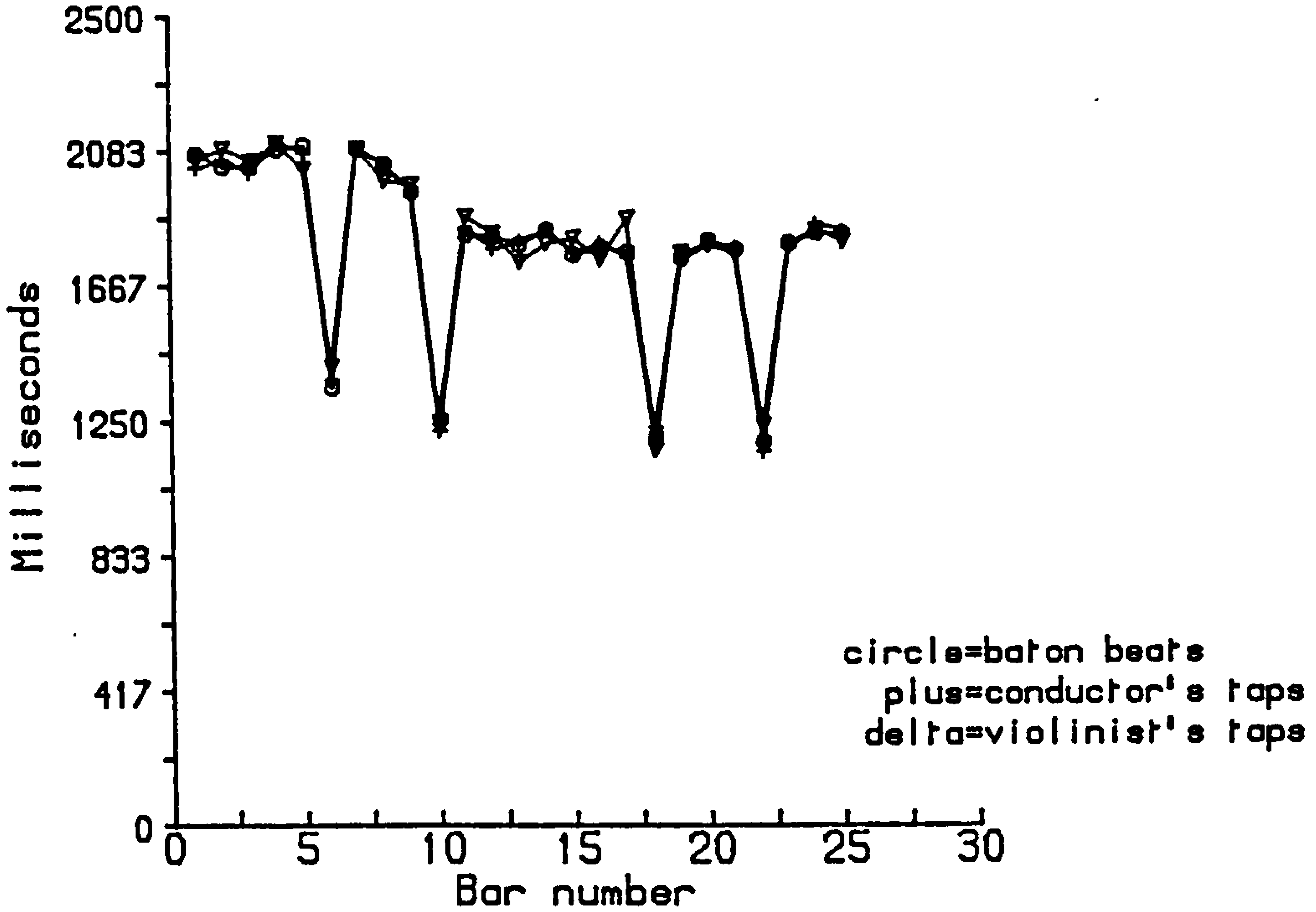


Figure 3.26
Bar lengths
Baton beats and taps
Hinke-Tanz, first trial

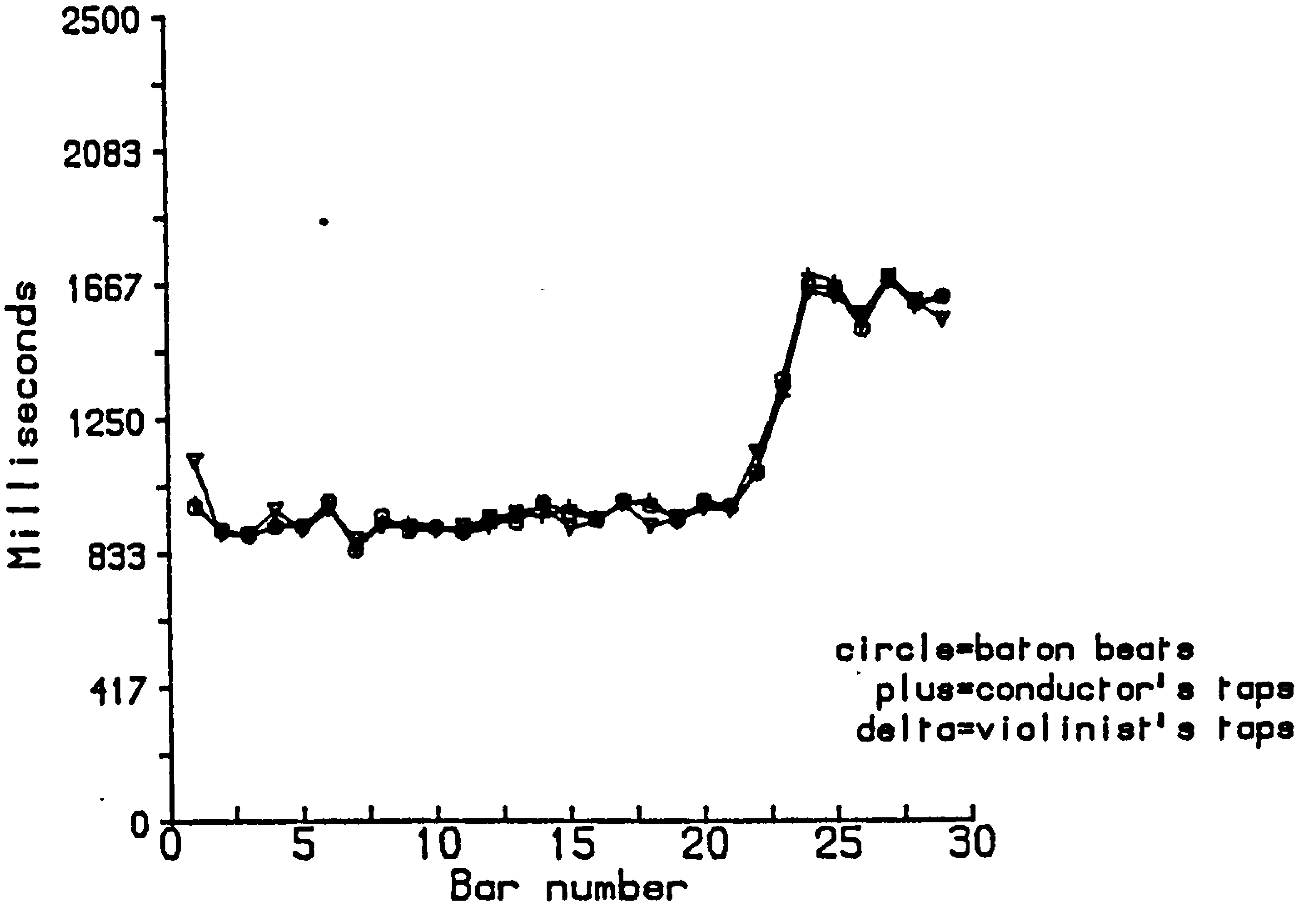
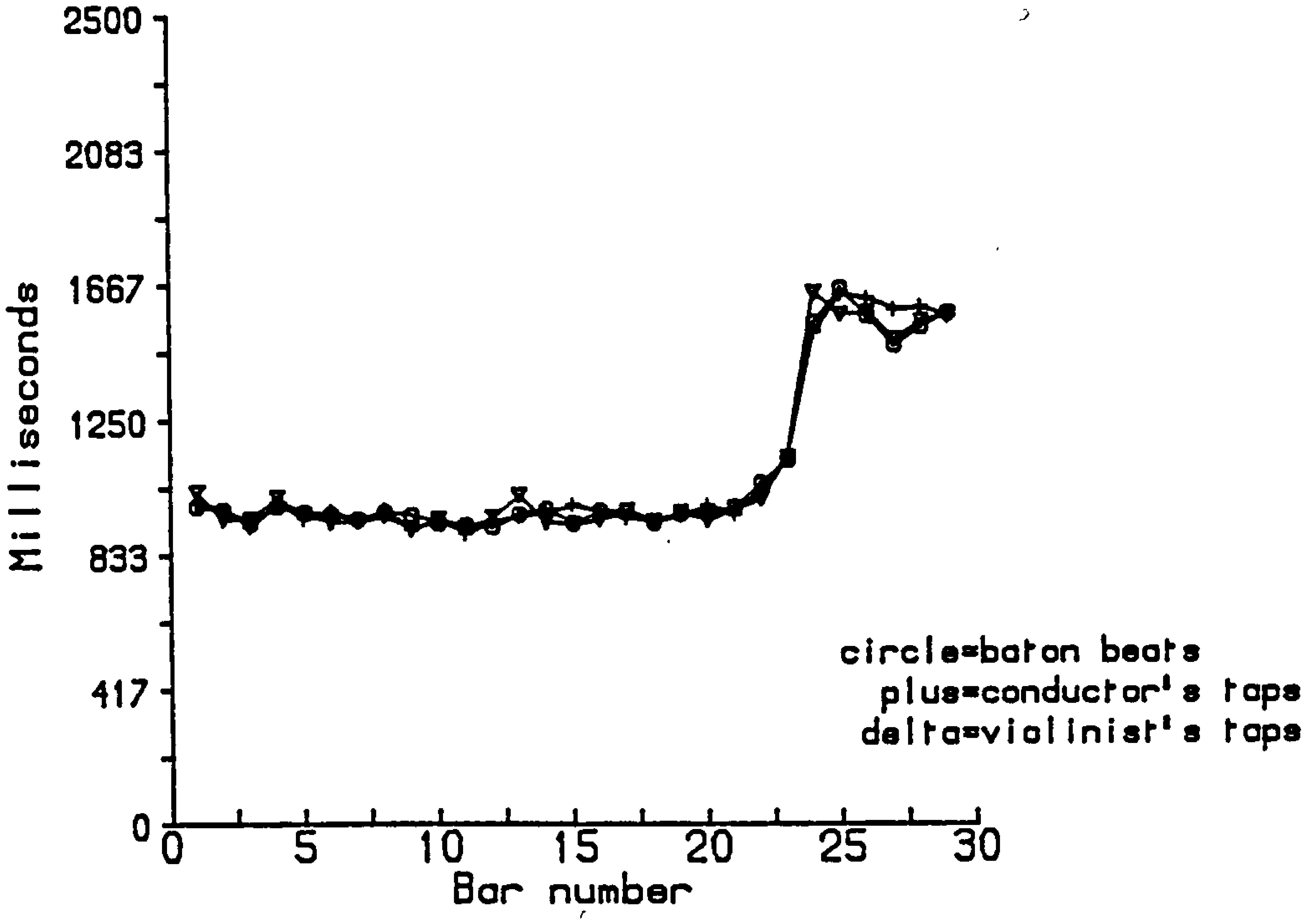


Figure 3.27
Bar lengths
Baton beats and taps
Hinke-Tanz, second trial



Conclusions

(1) The feature of the baton trajectory that corresponds to the beat may be taken to be the vertical minima, or the transition from downward to upward vertical velocity.

(2) There is significant patterning of the baton beats, possibly used to emphasise the first beats in the bar. The foot taps are more regular. The violinist has expectations as to where the beat is to be, which could be generated by the rhythm revealed in her foot tapping. However, she is also able to respond to the patterns indicated by the conductor's baton. Thus the process of continuous coordination of actions is not one of static interval matching, but is dynamic and interactive.

(3) The structure that serves to coordinate these events is, in this case, the bar. The importance of the bar length, and the consequent need to clearly demarcate these lengths, may explain the emphasising of the first beats in each bar.

Chapter Four

The Principles of Communication.

Abstract

Musical output must be structured around certain requirements as to how and when the musicians are to play. When musicians are interacting, these requirements must be communicated in advance. The microstructure of a baton upbeat and downbeat, and the responding drum action, are analysed over a range of stylistic and temporal demands. The drummer alters output volume by holding constant a number of parameters and thereby reducing those he needs to control directly to one: the amplitude of the critical drum striking action. The conductor communicates the volume required in a similar fashion, by controlling the amplitude of the baton trajectory. The temporal location of the beat is communicated by preserving the schematic proportions of the upbeat and downbeat in time and space. This allows the drummer to anticipate a point in time at which his action may be targetted.

Introduction

In playing music, there are temporal requirements which are external to the movements of the player. Movements must then be structured around these requirements. If the rhythm is being set by another person, then there will be a series of points in time around which the player is required to coordinate his timing. These temporal requirements must be communicated. Musicians must communicate this information as to their intentions in advance, when making music together, in order to stay in time, as the following quote from Lang (trumpet, LSO) makes clear.

> "In the brass we need a good attack...we have to have a definite beat to come in there together...the worst is when they (conductors) come down and don't stop. You don't know where the end of the beat is."

Chapter two concluded that there are multiple interactive sources of information available to the orchestral player. In this chapter the focus is on the principles of communication per se. The sources of information have therefore been reduced to one, and the parameters of the communication narrowed down to the point where the situation is the simplest possible while still retaining validity. The retention of validity is essential because if we are to evolve a model which purports to explain at some level some aspect of a complex human behaviour, such as making music, we must be able to delineate in our exposition some organizing principle which remains relatively invariant- and thereby gives predictable results- over variations in conditions within the range of normally occurring behaviour.

The sole source of information in these experiments is the conductor. The sole recipient is a percussionist. The conductor is a suitable subject for study because his mode of communication is purely visual, whereas with other players, there will normally be both visual and auditory cues. The further restrictions on the conductor's actions are detailed in the methods section. Thus the question of this chapter is, how does a conductor communicate, with only waves of a baton, how and when the orchestra are to play? If we knew how this synchronisation was achieved with this minimum of information, then we would have a model which could underlie many other cooperative, participative musical phenomena.

The communication of information.

Dimensions of variation

The observeable features of the baton action that the conductor can control are: the distance the baton travels, the direction it goes in, start and stop locations, the velocity from moment to moment, the acceleration or deceleration, the total time taken in any particular phase of the movement, and the overall time allotted to the action. All of the above can be subsumed under three headings: direction, amplitude, and duration.

Direction

Direction is specified by when, in relation to the first beat in the bar, the music is to start. If the orchestra are to start on the first beat in the bar then the conductor's action is as in figure 4.1(a).

He establishes a rest position with a slight pause- then goes up in a curve, peaks, and drops straight down onto the beat. The curve is recommended by Boult (1943) to clearly demarcate the top of the trajectory. The beat occurs as the baton returns to the rest position. Boult gives this example. You rest the baton on an imaginary table in front of you, then lift and let it fall. The beat is when the baton returns to and taps off the table. Note that the notion of an imaginary table off which the conductor taps the baton is not as straightforward as it might appear, as Boult then goes on to say that it helps to clearly demarcate subsequent beats in the bar by beating them higher and higher relative to the first. Thus seven in the bar may be portrayed schematically as in figure 4.2.

This also helps to give the music a feeling of pushing on. So we must also imagine this imaginary table floating steadily upwards throughout the bar, then plummeting downwards to its own rest position for the start of the next bar.

If the piece is to start on a subsidiary beat- the second, third, fourth etc in the bar, then the conductor will often give the orchestra the full bar from the one "silently". In fact, one or two complete bars are often given, with an extra emphasis to indicate which bar is the first bar of music. This of course establishes a periodicity. However, it is also possible to give the start on the two, the three, and the four respectively. These are also shown in figure 4.1(b), (c), and (d) respectively. These starts on the first, second, third, and fourth assembled give the standard beat for a 4:4 bar, so each beat is given with the rest position as if it were immediately after the occurrence of the previous beat. The main remaining possible situation is where a start must be made between beats, as in, for instance, the Scherzo of Beethoven's Fifth Symphony or Franck's Symphonic Variations. In this case, the beat is made at the rest position so that the note occurs as the stick is in transit upwards. This is illustrated in Figure 4.1(e).

This is generally regarded as difficult. Even Solti has been known to have trouble here while conducting Beethoven's Fifth Symphony.

For the purposes of the experiment this directional variable was kept constant, making the assumption that the same principle of communication of a time-to-arrival would obtain in all the circumstances specified. One of the simpler versions was selected, the first beat in a bar.

The musicians were told that no counting-in beats were to be given. Just as when there are other musicians playing, this establishes another source of information, a periodicity, which could be used to establish a time-to-arrival at the beat. The aim was that the situation, while being entirely legitimate, should contain only the minimum of information. In this sense the sitution was the simplest possible: a time-to-arrival had to be derived and specified from one movement.

Figure 4.1

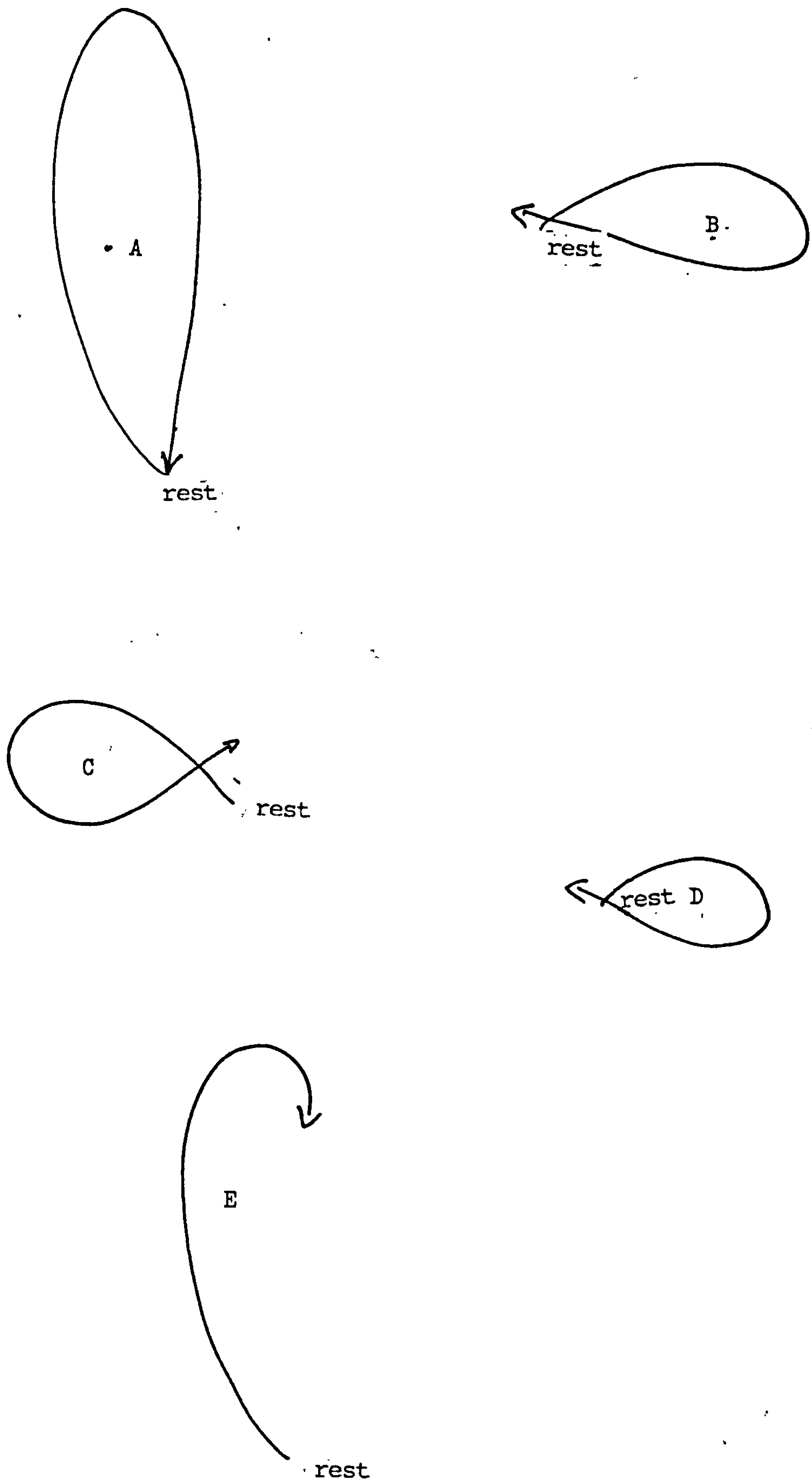
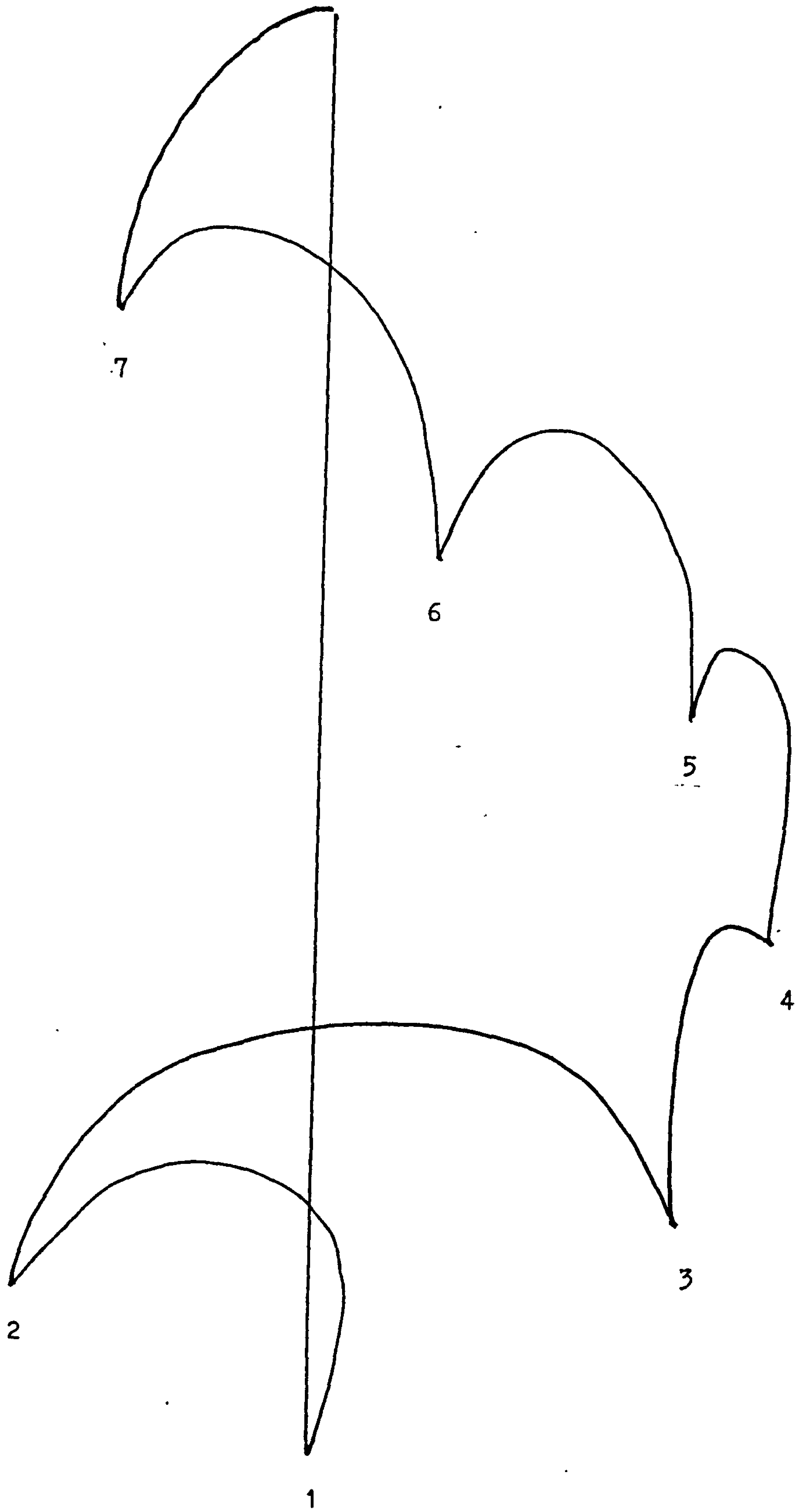


Figure 4.2



Amplitude of baton movement

According to McElheren (1966), the amplitude of the conductor's movement is employed to communicate "scale" or grandeur. This is really a compounding of two dimensions: The scale of a piece is its "gravitas"- light and delicate as with the Sugar Plum Fairy, or tremendous, heroic, Wagnerian as with Die Meistersinger. It also relates to the volume. Scale and volume often go together, but they are not strictly interchangeable terms. However, both determine the conductor's actions in much the same way. The grander or louder the piece, the larger the initial movement. "Grandeur", a synthesised single variable, will be used to refer to correlates of amplitude.

Duration of baton movement

The velocity of the conductor's movement indicates the tempo. The velocity may alter while the relative temporal proportions of the movement are preserved, or the internal dynamics may alter as well. This will determine the temporal location of the place where the percussionist is to play.

The aquisition and utilisation of information

The percussionist has a certain action required of him; to beat his drum. He can control the start position of the stick, the height from which it falls, the temporal locations of the peak positive and negative velocities and the terminal velocity on impact. The primary goals implicated in these mechanisms of control are (1) correctly targetting the hit time, and (2) an appropriate adjustment of the ensuing volume. The percussionist in these experiments proved able to locate his hit time so that it was effectively synchronous with the beat in the conductor's baton wave, as will be seen. How, then, does he get the necessary advance information and how does he use it?

Possible explanatory models. (1) Information aquisition.

Here in outline are four models for information aquisition. These will later be cross-matched with two models which describe how the information might be incorporated into the player's actions.

Model one: Starting Cues.

There is some feature of the baton downbeat which cues the start of the target-orientated phase of the drum action. This model depends on our being able to find this feature and establishing that from that point onwards, the baton and the drum action were synchronised.

Model two: Extrapolation from the rate of change of baton movement.

The player directly derives a time-to-contact from the deceleration of the baton as it nears its apex or the beat. This would imply that the moments of transition between accelerative and decelerative modes serve to demarcate the phases of the movement.

The question here is at what point does the information become unambiguous? Support for this model depends on evidence that the player could and is using the rate of braking on a regular and repeated basis to define any criterion point, such as the bottom of the baton trajectory. If an extrapolation of the rate of braking defines points in time which are only randomly related to the time of the tap on the drum, then that would weaken this hypothesis. If, on the other hand, there is a close relationship between the derived "point of contact" and the observed tap on the drum, and a systematic direction of errors, then that would support this model.

Model three: Absolute intervals between discrete events.

There are identifiable discrete events in the baton wave, which occur at regular intervals, such that a periodicity can be defined by the time taken by the baton to pass between two points which could then indicate the moment at which the baton would reach a third point.

Testing the hypothesis requires finding separate and identifiable components in the baton action which could serve as these timing points. We look therefore for any features of the action that are held constant over repeated trials within the same condition. Having decided which are the pivotal events which synchronise the actions of the player and the conductor, we then look for a systematic relationship in the errors made.

Model four: Schematic representation and continuous monitoring.

The player constantly monitors the baton wave, comparing the actual trajectory from moment to moment with an aquired schematic trajectory, launching the playing action when the perceived discrepancy between the two trajectories is reduced to some minimal or criterion value.

If there are action components that are held constant, for example, lapsed times or distances between certain points on the baton trajectory, then this would support a discrete events model. If, on the other hand, the various phases of the baton action preserve over trials only the same relative proportions then this would support the idea of an overall schematic representation of the ideal baton arc against which the actual one would have to be constantly compared.

Temporal limits on models

Are all aspects of the percussionist's action equally strictly determined? McElheren suggests that a conductor indicating a beat is like a man throwing a ball against a wall who has the additional task of communicating to another person who also has a ball when his ball is going to hit, so that they can throw theirs and hit at the same moment.

One of the subjects, D.R., developed this analogy. While the man has the ball in his hand, he controls it. Then his fingers have to open and the timing of the impact on the wall is no longer under his control. So the second person, in order that his ball should hit the wall at the same time as the other ball, must have made a certain prediction by that release time as to when that impact-time is to be, and bases that prediction on information derived from what he can see. He sees when the other person starts to throw, when and how the ball is released, whether the throw is gentle or hard. With practice, the second person can predict accurately when the other ball will hit the wall and can time the throw accordingly.

This suggested that there might be a time in the drum action when no further control of timing is exercised- i.e., that there is a ballistic component. This was borne out by the data. If there is a ballistic component of the drum action, then there will be a time at the initiation of the ballistic phase when the drummer has effectively made a decision where the beat is going to be, and plans the timing of his move towards that estimated target time. If this is correct, it should be possible to identify different phases in the drum action, with the critical phases tightly tied to the external timing constraint. This would require examining the data for evidence that would support the idea that the drummer's action was in some sense determined by a specific time, so that the location of that time point in the overall baton wave could be identified. This would make it possible to specify how much information was available to the percussionist at that time.

Possible Explanatory Models (2) Information utilisation.

The next question is how is the information, once picked up, used by players in the control of their actions? The players might be able to modify ongoing actions in response to a perceived potential discrepancy between where they are going to put their beat, if they continue with the current program unchanged, and where that beat ought to be (as defined by the rest of the orchestra or a semi-independent internal assessment of beat location). This would be possible if the players were targetting the beats in advance. Alternatively, players might be confined to modifying subsequent actions in the light of an actual discrepancy between what they have done and what everyone else has done. This would be the case if the player's timing programme was triggered by a previous beat or similar event. Bound up in this question is a further question on the utilisation of information, as to whether the feedback information is used to continually alter output, or whether the musician is restricted to introducing discrete corrections. The drawback associated with the former approach is that there is a possibility of hysteresis, that associated with the latter approach is that there might be a detectable unidirectional divergence away from the correct time unit.

Shaffer (1982) notes that the idea that movements are structured towards temporal goals (targetted) is fundamentally different from the supposition that movements are triggered by events. Movement triggering implies that the movements are pre-prepared and initiated on some cue. The movement targetting hypothesis permits the corollary that the motor system responsible for constructing movements could translate a given time interval, which could be derived from a visual stimulus flow (Lee 1980) into a movement trajectory having that duration. Thus the motor system could act as timekeeper, realizing a time scale in a movement trajectory.

Sudnow (1978), and Kelso et al (1979), found that in bimanual movements to targets of varying distances, the hands tend to start and finish together, although different velocity profiles are required to do so. They also found that velocity profiles tended to peak at the same time. (Sudnow simply says "midway through" the movement.) Shaffer points out that this requires that timing parameters are involved in coordinating the actions, with the parameters taking on the same value for each hand in the bimanual tasks. One of the key parameters is obviously the temporal end-point of the movement. This temporal target could be provided either by an internal representation of time, or by an external factor. These findings mean that movement targetting is implicit in that experimental situation.

When referring to external factors, the alternative models will be termed (1) event triggering and (2) event targetting. Event triggering means that the subject who is monitoring the information flow uses a key event in this flow to trigger the initiation of the required response. Event targetting means that the subject derives from the information flow a time-to-arrival at a key event, and that this temporal terminus is used to scale the required response.

Possible explanatory models (3) Information aquisition and utilisation.

The two models of information assimilation, event triggering and event targetting, integrate with the four models of information aquisition given earlier as follows.

(a) Model one, that the drum action is cued, is compatible with the

event triggering hypothesis, but not with event targetting.
(b) Models two to four are all compatible with event targetting. The time to arrival available from the rate of deceleration (model two), or the discrepancy between the current time and the time predicted by a periodicity (model three) or between the actual and the schematic trajectory (model four) could be translated into the terminal target temporal parameter of a goal-directed movement.

How would the data support one model of information assimilation rather than another?

A general difficulty in deciding between these models is that features of the data may be implicated in more than one model. The distinctions between them may then be based on quite small differences in the predicted outcomes of model applications. For example, if the drum action proved to be tied to the moment of peak negative velocity of the baton, that could indicate either that a rate of braking strategy is being employed, or that the turnaround in acceleration is the triggering cue for a pre-prepared action. Similarly, if there was an event in the baton trajectory that would allow an appropriate predictive periodicity to be established, but which was so located that it could also serve as a cue, then a similar ambiguity would exist. The distinction here could be made by defining those phases of the baton trajectory where a cue for action might exist, and then examining the variances of the goal-directed phases of the drum action with respect to the cue at the beginning and the baton beat at the end. If a movement is pre-programmed and triggered, then the variances should be similar at either end. If a movement is targetted, then variances should be least at the target. Further, the location of the candidates for cues in the baton trajectory may be examined for consistency across trials, and errors here correlated with observed drum beat errors.

The choice between models becomes more complex if a calculated discrepancy, either between a schematic representation and the observed trajectory, or between a periodicity derived from two previous points and the actual moment in time, could be said to act as a cue. This is because in neither case is there an actual observeable feature of the baton trajectory that can be unambiguously identified. However, this is only tenable where there is a known time interval, in which case the error pattern in the time allocations should be reflected in the errors in the drum beat placing. Such an analysis cannot be extended to the schematic model where the time allocations are proportionate, as here there is no point which could be said to serve as the cue.

The location in which candidates for cues may be narrowed as follows. Event triggering must involve a reaction time (RT) delay between the cue and the initiation of the response action. This problem cannot be solved by allowing for pre-cue cues, as this would simply entail an infinite regression. It can only be avoided by allowing an RT accomodation within the response action timing, and identifying a pre-target cue. Thus the question is, what candidates are there for the pre-target cue?

If the player could not accurately determine the temporal location of the beat until it had actually occurred, he would be restricted to following a certain time behind the conductor, which would determined by his RT. This would be seen as a constant offset between the beats of the conductor and the drummer. McElheren, however, states that musicians cannot really "follow" a conductor as this would mean being late. When the requirement is to play "on" the beat then they do just that. They anticipate and perform with the conductor. Moore (1943) makes exactly the same point about accompanists and singers.

> "We rehearse in order that we shall not have to follow, that we shall be able to anticipate, and march abreast of the soloist."

There are conductors who like their orchestra to play behind them- such as Gibson, formerly of the SNO- but this does not mean that the orchestral players are limited by their reaction times. Firstly, remembering the different response characteristics of the different instruments, you might have to suppose that RT's varied by orchestra section. Secondly, there are situations where musicians can come in simultaneously; this is demonstrably so. Michon (1967) states that a 25ms offset between note onsets allows detection of the onset order. There is certainly no reason to suspect that acuity is any the less in the perception of the difference in time between a conductor's beat and an instrumentalist's beat. The data reported here demonstrates that subjects could achieve a higher degree of synchrony than RT.

The situation is summed up by Pay (clarinet, LSO)

> "It depends on the piece, how closely the players will want to hang on the beat. If you watch some orchestras, they play about a quaver, sometimes a crotchet behind what the man is doing. Obviously, these things are a convention."

Solti, for example, likes his orchestra exactly on the beat, although he does not give very clear beats. Toscanini and Scherchen also liked immediacy.

There is another possibility: that there is some other event in the baton wave, immediately prior to the beat, to which the players respond as if it were the beat. With an RT delay, the result of their response would sound on or near the conductor's actual beat, thus resulting in the temporal proximity that can be observed. If this is the case, then (a) there must be some identifiable feature in the baton action that could be the actual trigger event, and (b) any variation in the location of this trigger event with respect to the location of the conductor's own beat should account for most of the variation between the conductor and instrumentalist's terminal beat locations.

Thus immediate restrictions on the potential candidates for the pre-target cue are introduced by RT values. The figures adopted are given in table two in the methods section of this chapter.

Note that the IBI at prestissimo, 340ms, is only just over the adopted value for RT (300ms). If the players target their beats in advance then this would just allow individual beat targetting and incorporation of corrections to perceived errors on previous beats. If, on the other hand, players operated on an event-triggering schedule, then the shortness of this IBI would preclude almost every candidate for the pre-target cue other than the previous beat. This would in turn indicate that corrections could not be to subsequent beats, but only to subsequent plus one beats. In chapter two it was reported that detection of asynchronies and accomodation corrections into the targetting of the subsequent beat obtained even at prestissimo, near the threshold at which beats can only be conducted in multiples or pre-programmed as a unit (for example, a drum roll), rather than individually. This supports a targetting rather than a triggering hypothesis, with the proviso that adjustments must be very rapid and smoothly accomodated into the targetting of the subsequent beat.

Summary

This section described how models of information assimilation will be tested and compared in terms of the degree of support afforded by the presence of appropriate features in the data, in the appropriate location of those features in movement phases, and in terms of lawful predictive validity and corresponding error clusters.

The triggering hypothesis depends on there being candidates for the pre-target cues. If these are not found, and in the movement phases bordered by the beat and the RT value, then this would undermine the triggering hypothesis.

What would remain is the targetting concept, which requires that the player is able to anticipate the conductor, which in turn requires that there must be an information parameter that would permit a lawful and regular extrapolation or comparison that would predict the time delay before the beat to come, plus the rate of change in the residual delay.

Methods

(1) Subjects

There were two subjects. G.T. was the conductor, D.R. was the percussionist. Both were from the nearby Music Department. Brief biographies are given in appendix four to indicate the amount of experience and level of skill.

(2) The instrument

The instrument chosen was a drum. The rationale for the selection was that the situation had to be musically legitimate but as simple as possible in that every part of the playing action had to be external and observeable. With brass or woodwind some of the control is done with the palate, lips, tongue, and chest where it is difficult to precisely differentiate events. A similar problem arises (with the recording technique used) with strings, because hand-held instruments move when the musician moves. Thus for this experiment, a percussion instrument was found to be ideal. A Premier snare (or side) drum, 36 cm in diameter, was used.

One of the principal measures in this experiment was the output volume of the drum. One of the ways in which this can be controlled is by varying the site of the impact of the drumstick on the drum. This would have been difficult to measure, so this possibility was precluded by chalking a small circle on the drum within which the drummer was required to play. The circle was 10 cm in diameter, its near edge was 7 cm from the rim of the drum nearest the drummer.

This requirement was not unduly constraining.

(3) Data recording

The Selspot movement monitoring system was used to record the position of two diodes- one fixed to the baton tip, one to the tip of the drumstick. Data was stored in a PDP11 computer.

(4) Subjects' positions

The conductor and the drummer sat facing each other, 2.0 meters apart. The camera recording each player was set beside the other player, which avoided scaling problems. Photographs 4.1, 4.2, and 4.3 in appendix two show the positions of the players, cameras, baton and drum.

(5) The musical scenario

This experiment was concerned with starts. A start is when the conductor brings in a section or the orchestra in unison. A successful start is a complex achievement, bearing in mind that not only might there be different movement time characteristics and delays associated with each instrument but that there might also be someone whose task it is to play off the beat, which means that they must identify the correct moment of the beat in advance, then offset from it. The conductor must therefore give a clear indication of where the beat is to be in order to enable the players to start their actions at the appropriate time and establish ensemble. The conductor must also, at this point, confirm the volume at which the musicians are to play.

The start was selected for study because the other sources of timing information (for example, the ensemble of the players) are not present, nor can the player rely on an internal clock as it could not have been set to a rate or a start position. There is thus a basic minimum of information, yet as it is a legitimate situation, it is a valid paradigm of musical synchronisation. Subjects' reports indicate that

> "The start is the best moment to study because at that moment the communication between the conductor and the orchestra is at its most intense."

This indicates that it is perhaps the most important moment for the conductor's time-keeping function.

The conductor gave the introductory beat, the percussionist's task was to synchronise his tap on the drum with the beat given by the baton, and to reflect the grandeur communicated by the conductor. The player was requested to play "bang on the beat" as best he could, and to avoid deliberate syncopation or other off-beat playing.

(6) Procedure

The start of each recording was signalled by a tone. The musicians engaged each other's attention, then started. Each recording lasted 4.9 seconds.

The percussionist knew in each case at which grandeur and tempo he was to play. It would have been unrealistic had he not. Note, however, that prior knowledge of the grandeur and tempo does not mean that the player does not need to monitor the conductor. Orchestral players normally have a tempo written on their scores, and generally they will know- from rehearsals- whether the conductor's preference is to force the pace on or to go slowly. However, for the initial synchronisation, and to gear subsequent movements to the exact rate that is to ensue they still watch the conductor closely, because no performance is ever precisely repeated.

(7) Design

Amplitude and duration of baton movement were varied. The aim of the experiment was to ascertain how the percussionist might obtain and employ the information required to correctly time his tap on the drum and gauge the output volume required over a normal range of conditions. There were thus two factors in the experiment. The range of amplitudes (for grandeur) was simply: small, medium, and large. The end-points were, respectively, the smallest and the largest movements that the conductor would normally make on starting a piece, with one set in the middle. The control here was not precise, but at each level the conductor kept the movement as constant as possible by imaging the piece that they were about to play.

The range of tempi was similarly selected- the slowest being larghetto (50 beats:min or 1 beat:1200ms) this being the slowest

G.T. would normally go without subdividing. The fastest was prestissimo (176 beats:min or 1 beat:340ms) this being the fastest he would go while still conducting individual beats rather than multiples. The midrange was moderato (78 beats:min or 1 beat:770ms) which was selected because the inter-beat-interval was of a value midway between the two extremes. At each change in tempo, the conductor would leave the room and check the tempo on a metronome. This was to ensure uniformity across trials.

Thus there were nine cells, as the two dimensions were cross-varied.For each combination there were ten trials, giving a total of ninety trials. Table one gives a summary of the variables.

<u>Table one</u>

	Grandeur		
	(1)	(2)	(3)
Tempo	Small	Medium	Large
(1) Larghetto	G1T1	G2T1	G3T1
(2) Moderato	G1T2	G2T2	G3T2
(3) Prestissimo	G1T3	G2T3	G3T3

(8) <u>Specification of parameters</u>

The following values for reaction time (RT) are taken from Stelmach (1982), who breaks down RT's by information modality.

<u>Table two</u>

Information Modality	Reaction Time
Visual	180ms
Auditory	160ms
Tactile	140ms
Kinaesthetic	120ms

The last figure is from Chernikoff and Taylor (1952). Rosenbaum (1980) provides details of RT when pre-programming of the movement is possible, with the number of dimensions of information as the independent variable.

Number of choices	Reaction Times
Zero	300ms
One	450ms
Two	600ms
No previous information given	700ms

As the musicians could know all the dimensions of the movement, the proper comparison is with the zero choice situation.

Results

Part one: Controlling the drumstick

How does the drummer control the timing and force of the impact of the drumstick? What parameters are controlled, and how is it done?

(1) Control of drum volume

The volume output will be determined by the displacement of the drum skin. The displacement is determined by the momentum of the stick on impact. Momentum is determined by the effective mass multiplied by the velocity of the stick. Effective mass will be determined by the mass of the stick plus the mass of the part of the arm involved, corrected for the angle and location of the impact, which were held constant. If effective mass is held constant, then velocity is the controlling variable as it directly determines the "power" (momentum) of the impact. Note that velocity is equal to distance divided by time, under conditions of constant acceleration.

Thus the drummer's output volume could be adjusted by controlling one parameter, the terminal velocity with which the stick hits the drum. This proved to be the case. Velocity was varied by both grandeur and tempo. The greater the grandeur the higher the terminal velocity. The faster the tempo, the higher the terminal velocity also. The variation of terminal velocity by tempo was not, however, as marked as it was by grandeur.

Note that subjects' reports make it clear that it is possible to hit quickly and lightly, or quickly and powerfully, etc. It does not follow, however, that power is somehow separate from velocity. It could well be, for example, that the statements refer to the control of effective mass by altering the strength of the linkage between the hand and the drumstick.

Terminal velocity, by condition, is given in table three, and plotted in figure 4.3.

Table three

Part one: Terminal velocity of stick. Units are in meters per second

Grandeur-	Small			Medium			Large		
Tempo-	largh	mod	prest	largh	mod	prest	largh	mod	prest
Mean	1.17	1.26	1.55	2.23	3.95	2.26	3.84	4.69	6.83
S.D.	0.33	0.22	0.44	0.61	0.47	0.44	0.51	1.78	1.53

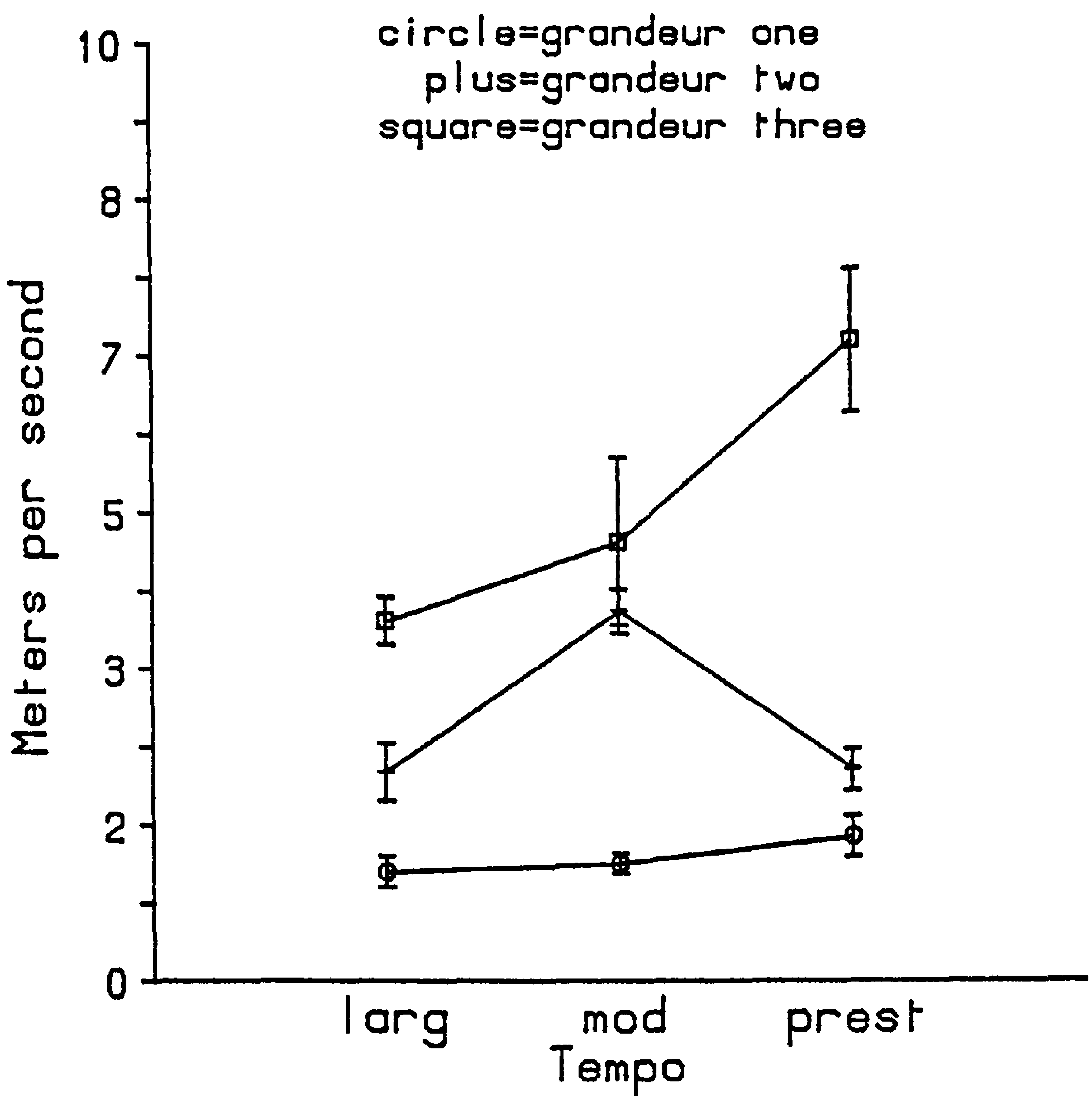
Part two: Terminal velocity by (a) grandeur and (b) tempo

	Mean	S.D.
small	1.3	0.2
medium	2.8	1.0
large	5.1	1.5
larghetto	2.4	1.3
moderato	3.3	1.8
prestissimo	3.5	2.9

The next question is, does the drummer control terminal velocity by controlling amplitude, duration, or both? The answer is that the duration of a critical phase of the drum action is held constant, which reduces the number of parameters of control to one: amplitude.

This component of the drum action which is of near constant duration does not vary by either grandeur or tempo. It is possible

Figure 4.3
Terminal velocity at impact of stick on drum



to distinguish this phase by the very marked change in acceleration in the downward movement of the drumstick, just as Shaffer (1982) suggests. This point is labelled 'start run' in figure 4.4, a copy of a typical baton and drum velocity time series.

It proved to be the drummer's wrist action that was of constant duration. From the start of this phase of movement to the impact on the drum the mean time lapse was 71.1ms, with an S.D. of only 18.5ms across all conditions. Table four gives the wrist action times, by condition.

Table four

Wrist action times. Units are ms.

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	73.4	64.0	63.3	65.6	74.9	71.1	109.7	74.9	58.3
S.D.	13.9	11.3	17.6	9.0	15.6	16.9	20.2	16.5	11.0

The fact that there is a critical phase of action which the drummer holds temporally constant allows him to control the terminal velocity on impact, and thus the output volume, by controlling only one parameter, the distance travelled by the drumstick.

In controlling this distance, the drummer initially reduces the degrees of freedom by starting each replicate from a regular 'ready position'. The height of the drumstick above the drum at the start of each recording did not vary by either grandeur or tempo. The mean height was 24.2mm, with an S.D. of 11.2mm over all conditions. Table five gives the initial heights by condition.

FIGURE 4.4 MEDIUM GRANDEUR, MODERATO

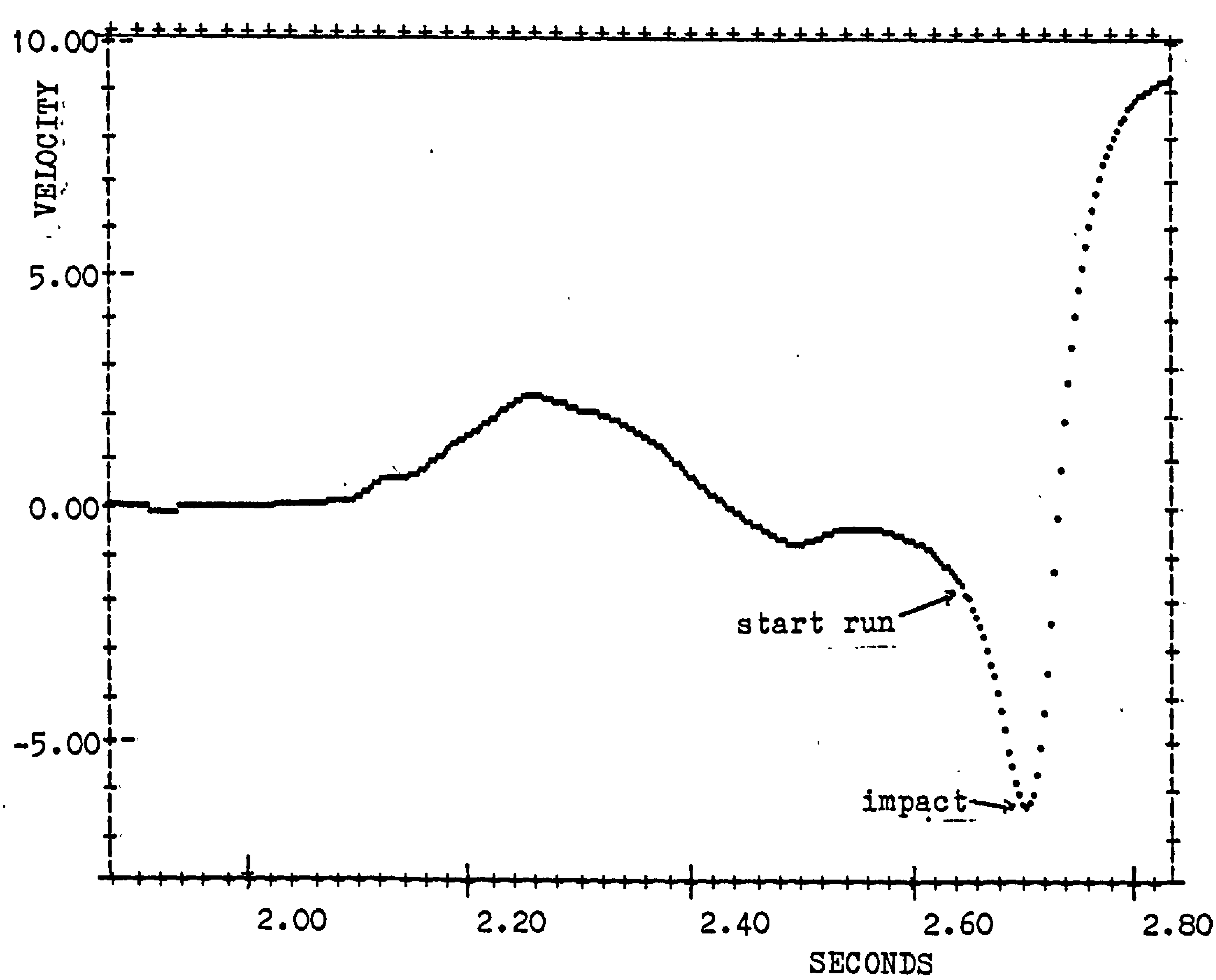


Table five

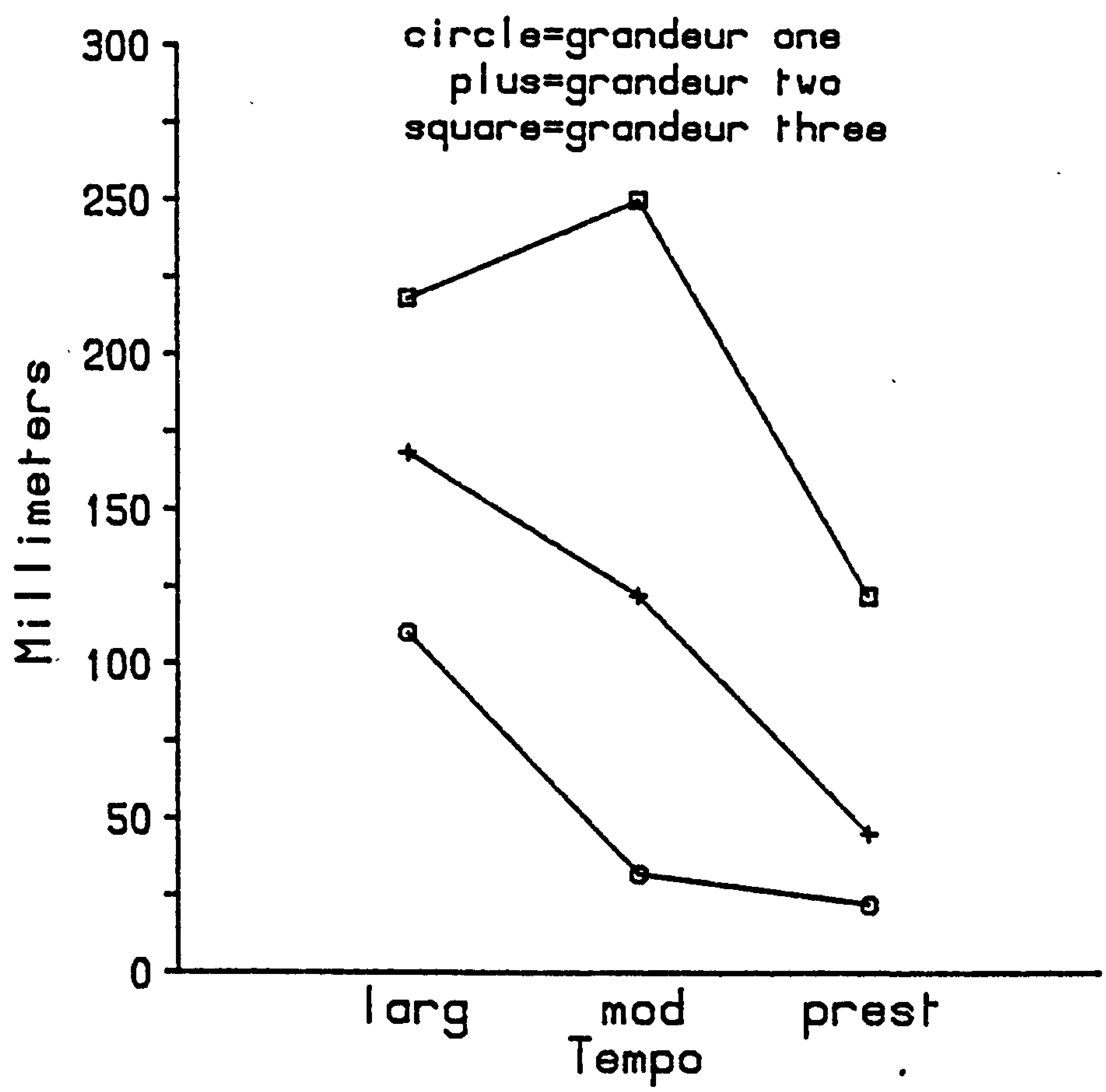
Initial drumstick heights. Units are millimeters

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	23.7	21.8	16.3	20.4	31.1	13.9	12.9	17.4	26.8
S.D.	7.2	6.6	9.6	6.4	11.5	7.8	8.8	6.7	8.8

The distance the drumstick was then raised before commencing the drop on to the drum varied by both tempo and grandeur. At larghetto, the stick was raised higher than at moderato (with one exception, at the large grandeur), which in turn was higher than at prestissimo. Thus the rise height is in part a function of the time available. Furthermore, when the drummer is to play at the large grandeur, the stick is raised higher than when he is to play at a medium grandeur, which is higher than the small. The figures are plotted in figure 4.5.

The main rise height allows a margin for the control of the fixed interval wrist action start height. This wrist action start height does not vary by tempo but does vary by grandeur. The finding that there is no variation by tempo supports the conclusion that the unwanted volume that would otherwise be caused by the higher terminal velocity at the faster tempi could be controlled by varying effective mass. With the large grandeur, the wrist action starts higher than at the medium, the medium higher than the small. The wrist action normally started when the stick was already moving down, but in one condition (prestissimo, at the large grandeur) the wrist action started at the apex of the lift (this is why, in table six, the wrist action apparently contributes more than 100% of the

Figure 4.5
Drumstick rise height
from 'ready' position



terminal velocity). The wrist action start heights are plotted in figure 4.6.

The percentage of the terminal velocity built up in the course of the wrist action remains very constant across all conditions. The mean was 86.6%, the S.D. was 11.3%. The percentages, by condition, are given in table six.

Table six.

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Percents	80	78	93	79	81	81	91	83	113

Thus the main conclusions are that the drummer's output volume is controlled by varying the speed (terminal velocity) and thus the momentum or "power" of the hit. The critical phase of the drum action is the wrist movement, which contributes a constant 86.6% of the terminal velocity. This phase is demarcated by the change in the rate of acceleration as the movement changes from "ballpark" (approximate) to reference (accurate) timing. See figure 4.4. The duration of this phase is held constant, allowing the drummer to vary output by controlling one parameter, the height at which the wrist action starts. The main rise height of the drumstick also varies by grandeur and tempo, probably to allow sufficient margin for the critical controlling action to occur.

Finally, the durations of the delays between the start of the drum wrist action and the baton beat are no more variable than the asynchronies between the drummer and the conductor on the beat. Compare the S.D.'s in parts one and two of table seven.

Figure 4.6
Drumstick height above drum at start of wrist action

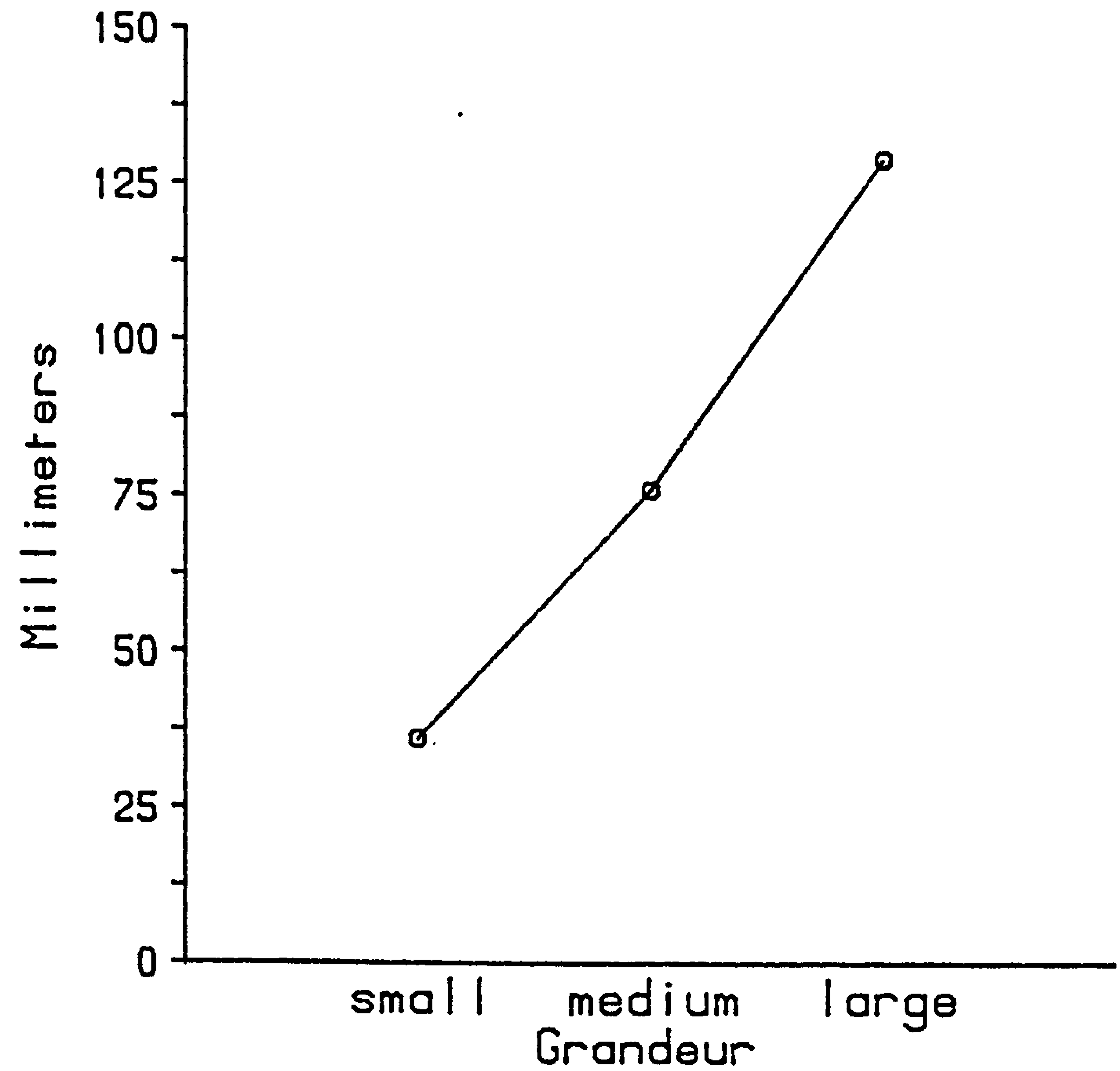


Table seven

Part one: Start wrist action-baton beat. Units are ms.

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	37.8	58.3	94.5	167.2	79.4	93.1	165.2	98.0	69.5
S.D.	89.3	52.0	19.8	40.2	34.2	36.5	41.6	33.4	24.1

Part two: Synchrony on the beat.

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	-37.8	-5.7	31.2	90.2	54.1	22.0	42.6	23.1	11.2
S.D.	84.2	52.8	18.9	45.3	21.1	37.5	44.9	30.1	21.2

The average asynchrony is 25.7ms, the average S.D. is 39.6ms.

Thus no further adjustment to movement timing occurs during the wrist action. It therefore appears to be an essentially ballistic action. This is borne out by subjects' reports. D.R. noted that at the very last moment before the impact on the drum it felt as if he was throwing the stick. He also commented that at that moment he had effectively lost control of what the stick would do. He compared it to using the momentum of a hammer to deliver the blow. Control was then progressively regained on the upbeat, which he referred to as "picking up the stick again".

All the information on which the drummer could make a decision as to where the beat is to be must therefore have been made available by the time before the impact at which the drummer has become committed to a time-of-arrival.

Part two: Controlling the baton

How does the conductor communicate changes in grandeur and tempo? What elements in the baton action are controlled?

(1) Communication of grandeur

There was no consistent relationship between baton rise and fall heights by tempo, at any given grandeur. There was, however, a clear variation by grandeur in the distance the baton travels in the Y-axis.

The height through which the baton rose from start to top was not the same as the distance through which it fell. The proportions, however, were held constant over all conditions. The average rise distance divided by the average fall distance gave a proportion of 93.7%, with an S.D. of 4.5%. Table eight gives the rise and fall heights, and total distance travelled, by grandeur. The rise and fall heights are also plotted in figure 4.7.

Figure 4.7
Baton rise and fall distances

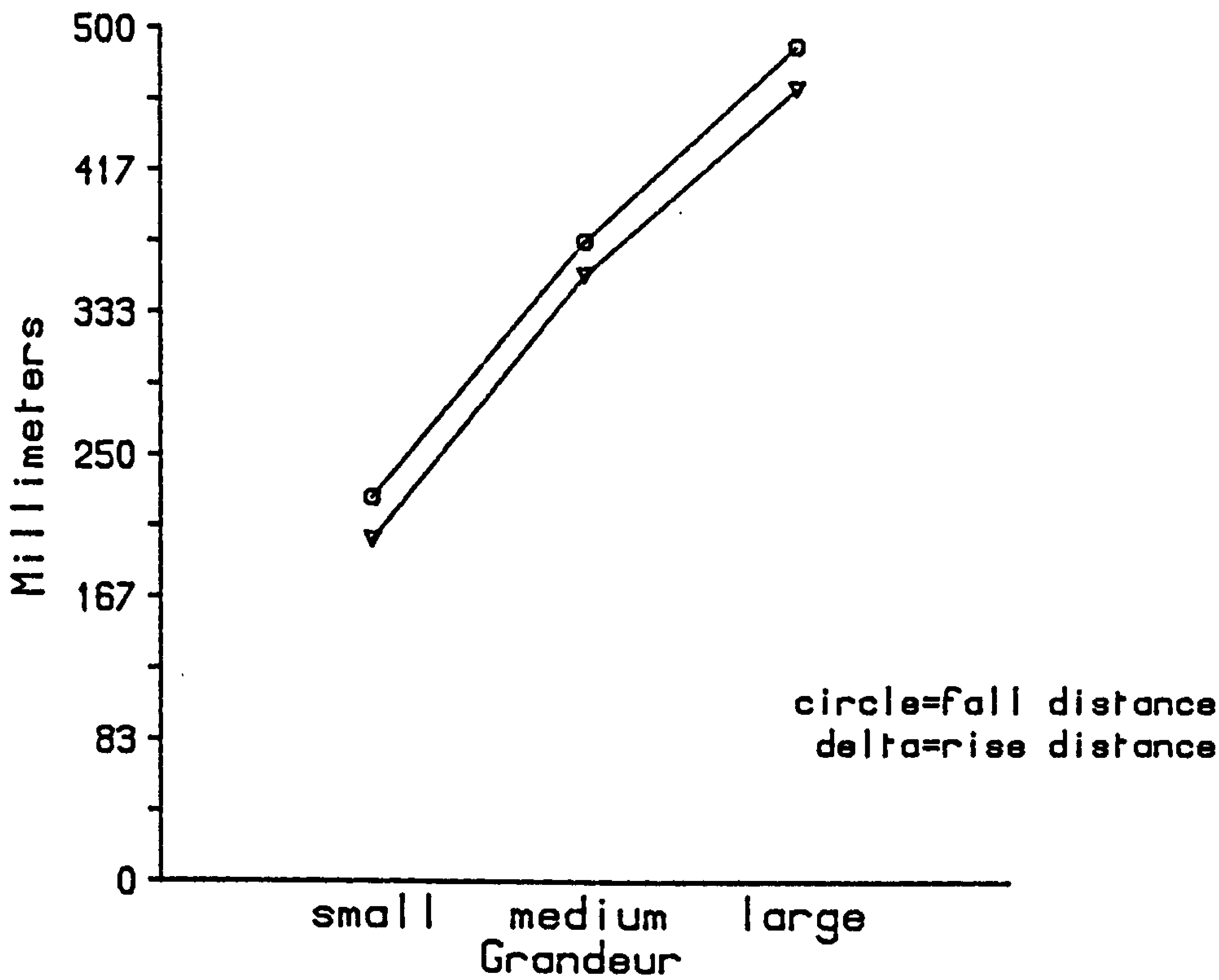


Table eight. Units are millimeters.

Part one: baton rise heights

	small	medium	large
Mean	199.3	359.9	466.1
S.D.	42.4	92.6	71.5

Part two: baton fall heights

	small	medium	large
Mean	220.0	376.6	486.4
S.D.	34.9	86.6	80.4

Part three: proportions of rise/fall

	small	medium	large
	90.6%	95.6%	95.8%

Part four: total distance travelled

	small	medium	large
Mean	419.3	736.5	952.5
S.D.	77.3	179.2	151.7

Grandeur, therefore, could be directly understood from the amplitude of the baton movement in the Y-axis.

(2) Communication of beat location

The conductor gives advance information on beat location by preserving both the temporal and spatial proportions of the baton movement. The time from start to top was not the same as the time from top to beat. The baton always took longer to come down than it did to go up. However, the proportion of the time spent going up to that spent coming down again was always the same. This proportion, across all conditions, was 75.4%, with an S.D. of 9.9%. Table nine gives the details, by condition. The rise and fall times are plotted in figure 4.8. The baton trajectory is portrayed schematically in figure 4.9.

Figure 4.8
Baton rise and fall times

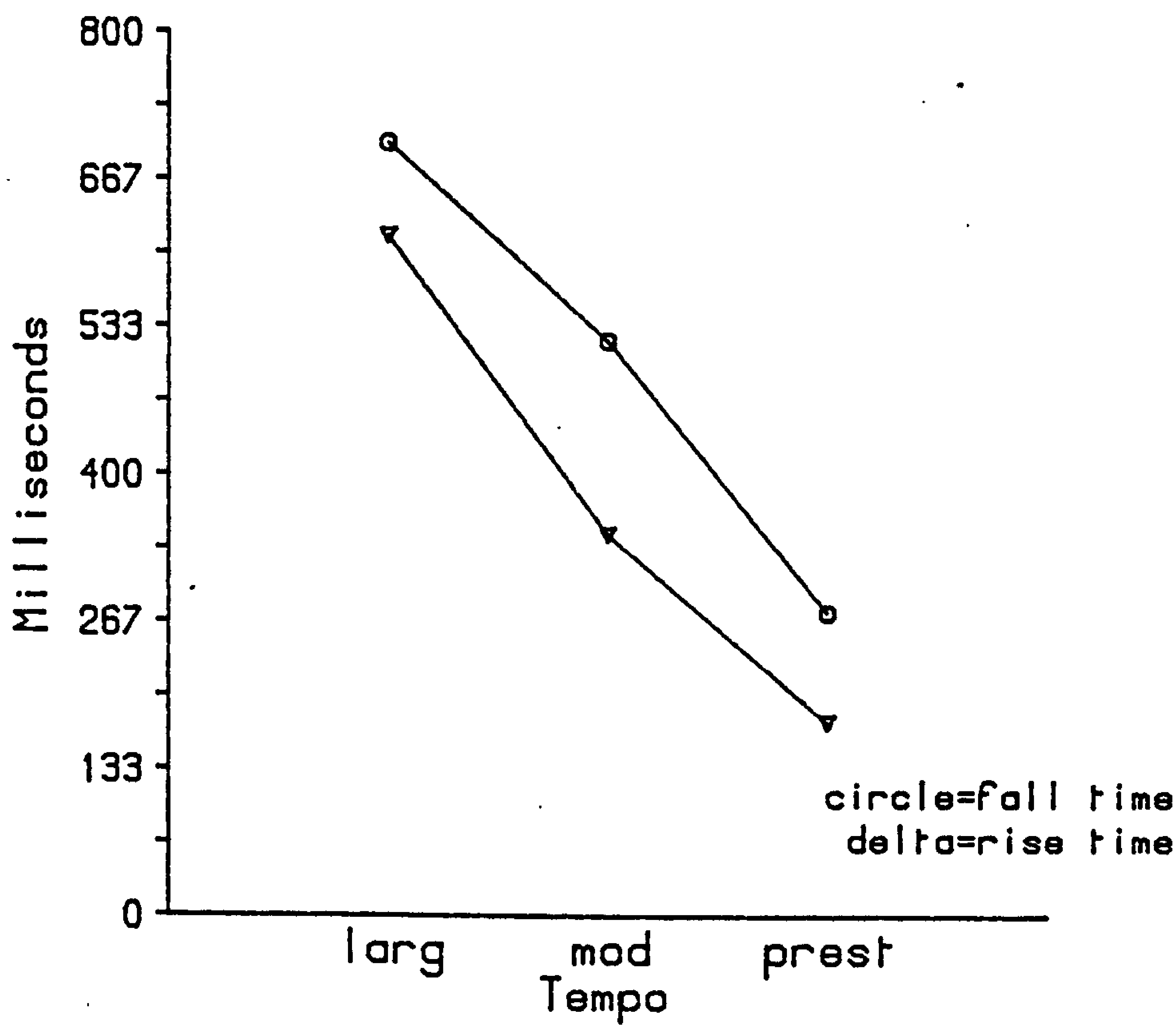


Figure 4.9

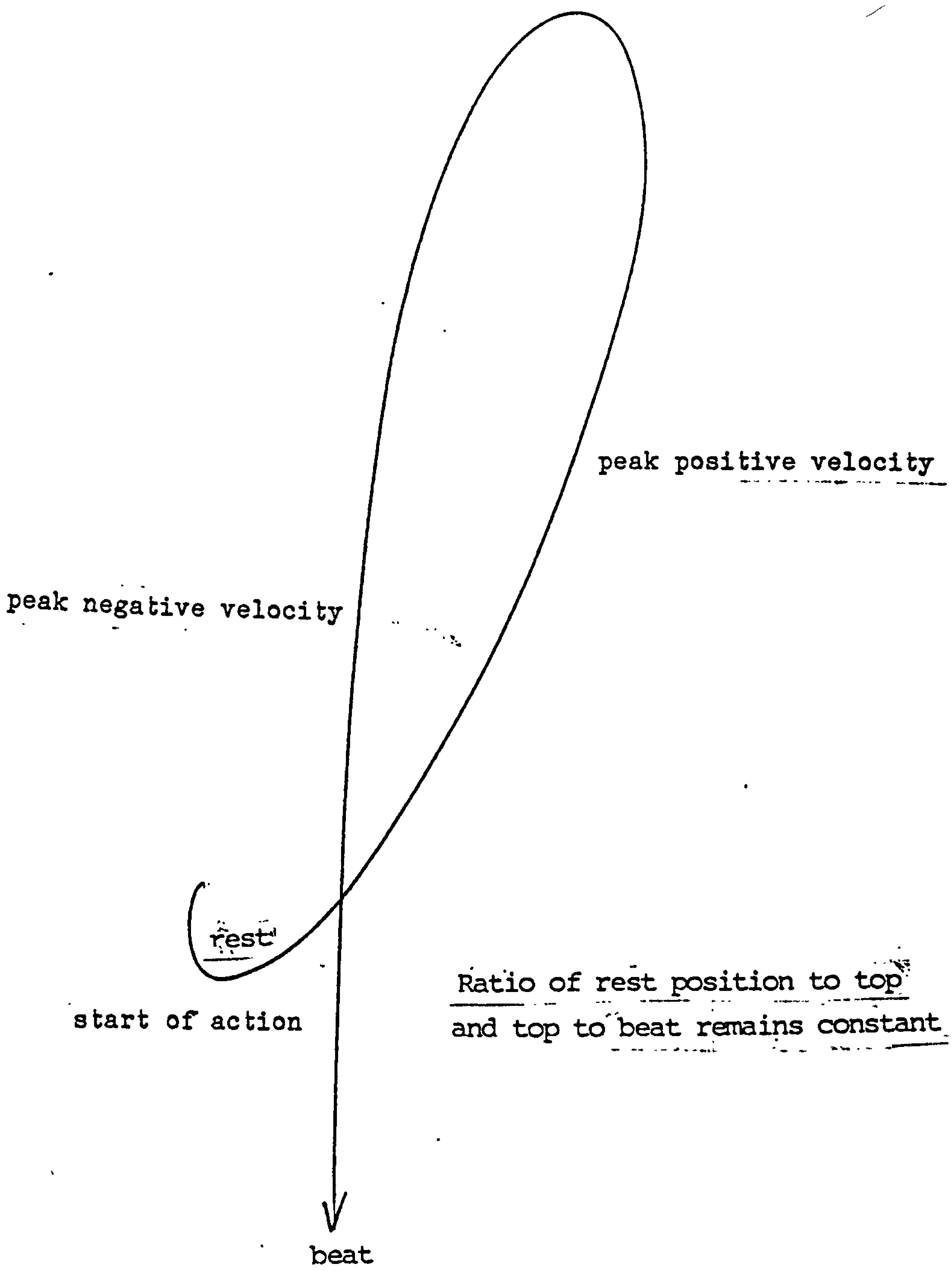

peak positive velocity
peak negative velocity
rest
start of action
Ratio of rest position to top
and top to beat remains constant
beat

Table nine

Part one: Baton start action-apex. Units are ms

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	696.8	370.5	185.2	517.2	340.6	208.4	617.6	340.9	182.5
S.D.	44.5	31.1	22.7	87.7	28.8	19.5	57.0	24.6	17.1

Part two: Baton apex-beat.

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	720.6	515.9	256.7	658.0	501.1	298.4	709.0	509.2	264.4
S.D.	29.4	16.6	14.6	89.5	26.8	25.6	36.6	12.1	21.5

Part three: proportions

Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
	96	72	72	78	68	70	87	67	69

Part four: proportions of upbeat to downbeat durations, by tempo

	Mean up/down proportions	S.D.
larghetto	87.0%	9.0%
moderato	69.0%	2.6%
prestissimo	70.3%	1.5%

There is a clear variation by tempo in the actual times taken between the start and the apex, and between the apex and the beat, but no consistent pattern of variation by grandeur. This is a diminishing relationship, in that the main distinction is between larghetto and the other two tempi.

In summary, the baton goes up a relatively short distance relatively quickly, then comes down a greater distance more slowly. Thus proportions of both time and distance allocations are generally preserved, therefore the average (but not the detailed) velocity profile is as well. Thus on seeing the distance travelled between the start of the baton movement and the apex, and on noting the time taken to move between these points, one could, knowing that the proportions of each would be preserved, anticipate the temporal and physical location of the beat. Note that the temporal and physical proportions are not identical, thus the velocity on the upbeat is on average higher than on the downbeat.

Part three: Synchronising the drum and baton

The baton arc preserves its temporal proportions over variations in tempo though the actual values, of course, vary. The drum action does not. Table ten gives the figures for comparison, by tempo (there is no consistent variation by grandeur with either baton or drum). Note that the drum proportions do not remain constant, but shift steadily between categories as the tempo increases. At larghetto the proportions are similar to those of the baton, but this is probably coincidental.

Table ten

Part one: Baton timing. Units are ms

	Upbeat		Downbeat		Percent	Total time
	Mean	S.D.	Mean	S.D.	Up/down	Up & down
Tempo						
largh	610.5	90.0	695.9	33.3	87.7	1306.4
moder	350.7	17.2	508.7	7.4	68.9	859.4
prest	192.0	14.2	273.2	22.2	70.3	465.2

Part two: Drum timing.

	Upbeat		Downbeat		Percent	Total time
	Mean	S.D.	Mean	S.D.	Up/down	Up & down
Tempo						
largh	509.2	60.4	570.0	103.23	89.3	1079.2
moder	366.9	22.9	346.6	53.4	105.9	713.5
prest	207.0	34.6	109.5	38.0	189.0	316.5

Since the proportions of the baton action are preserved, while those of the drum action are not, not every phase of the drum action can be geared to the baton action. The same conclusion follows from the finding that the total drum movement times are all shorter than the baton movement times, as the drumstick started moving after the baton. It also follows from the finding that the internal dynamics of the baton movement are much more regular than those of the drum movement. Table eleven gives the S.D.'s of the different phases, by tempo (there was no consistent variation by grandeur)

Table eleven

Part one: S.D.'s of baton timing. Units are ms

	Upbeat		Downbeat	
	Mean	S.D.	Mean	S.D.
Tempo				
largh	63.1	22.2	51.8	32.8
moder	28.2	3.3	18.5	7.5
prest	19.8	2.8	20.6	5.6

Part two: S.D.'s of drum timing.

	Upbeat		Downbeat	
	Mean	S.D.	Mean	S.D.
Tempo				
largh	147.8	30.5	109.0	52.41
moder	76.8	37.9	84.6	29.5
prest	44.1	10.9	24.7	12.3

Part three: Mean baton S.D.'s/drum S.D.'s, as percentages

	Upbeat Percentage	Downbeat Percentage
Tempo		
largh	42.7	47.6
moder	36.7	21.9
prest	44.8	80.1

The baton S.D.'s average only 45.6% (with an S.D. of 19.2%) of the drum S.D.'s, category for category.

The question then concerns the point at which the drum action engages, and how this is done.

Table twelve gives the degree of synchrony achieved on the beat, this time by tempo. These are the baseline figures against which we may compare synchrony at other points. Note that the values for the asynchronies are comparable with those found by Rasch (1979). Rasch found that the S.D. of asynchrony ranged between 23ms to 40ms with wind trios, and 35ms to 50ms with string trios. Note also that as tempo increases, the asynchrony and the variance of the asynchronies diminishes. This is shown in figures 4.10 and 4.11, for real and absolute differences respectively.

Table twelve

Part 1: Synchrony on the beat. Units are ms

	Real Difs		Absolute Difs	
	Mean	S.D.	Mean	S.D.
Tempo				
largh	31.7	64.7	56.9	28.9
moder	23.8	29.9	21.6	24.5
prest	21.5	10.0	21.5	10.0

Part two: Average asynchrony, over all conditions.

25.7	36.3	35.3	25.6

The only distinct features of the baton movement between the top and bottom that could be candidates for drum action cues (see figure 4.12) are the transition points between increasing and decreasing velocity, i.e. the peak positive and negative velocity points. A complication that has already been mentioned is that these would also be closely tied to the drum action if the drummer was extrapolating from deceleration rates, as they initiate and terminate the phases of acceleration and deceleration. To establish

Figure 4.10
Synchrony on the beat
Real differences

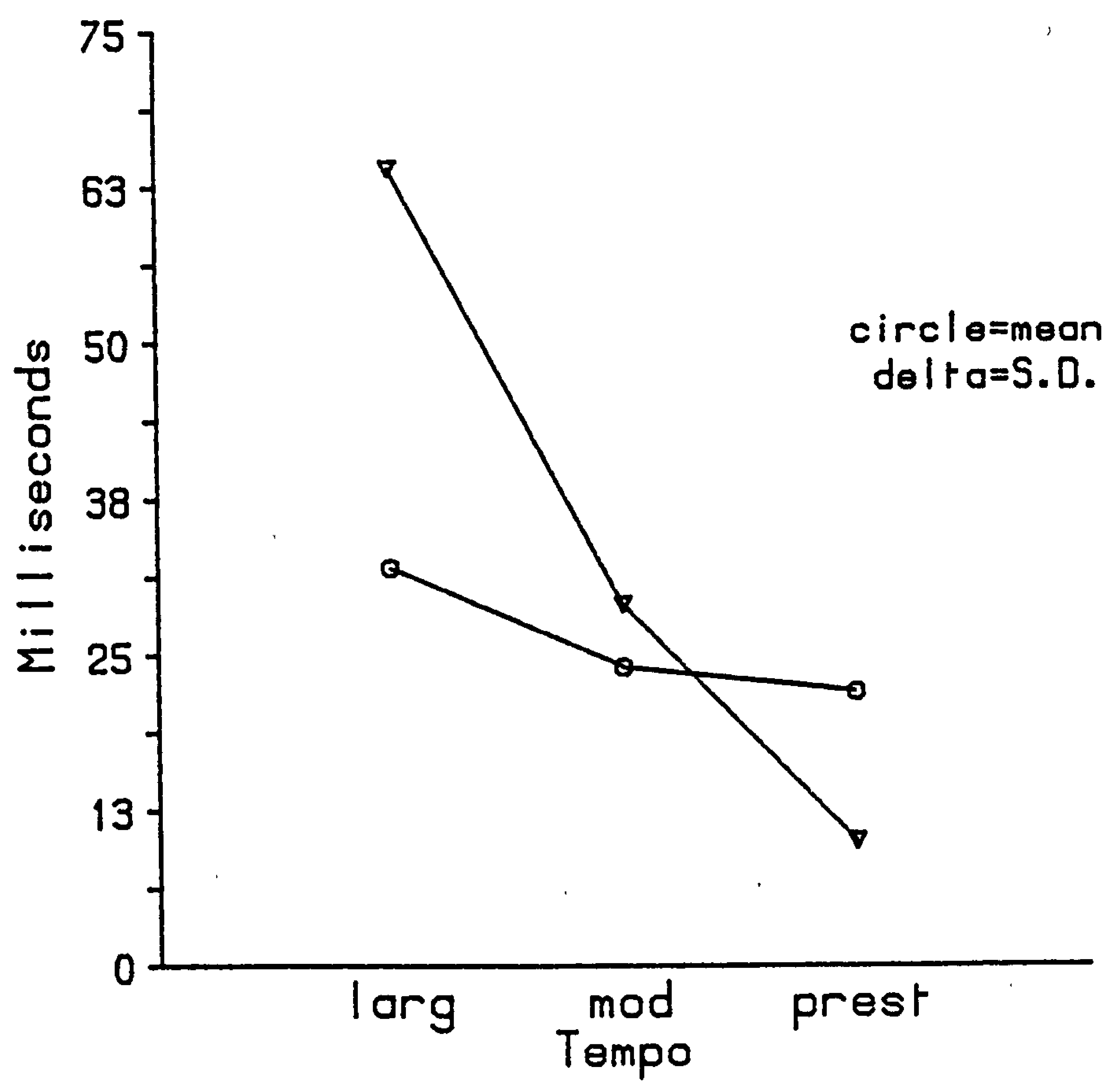


Figure 4.11
Synchrony on the beat
Absolute differences

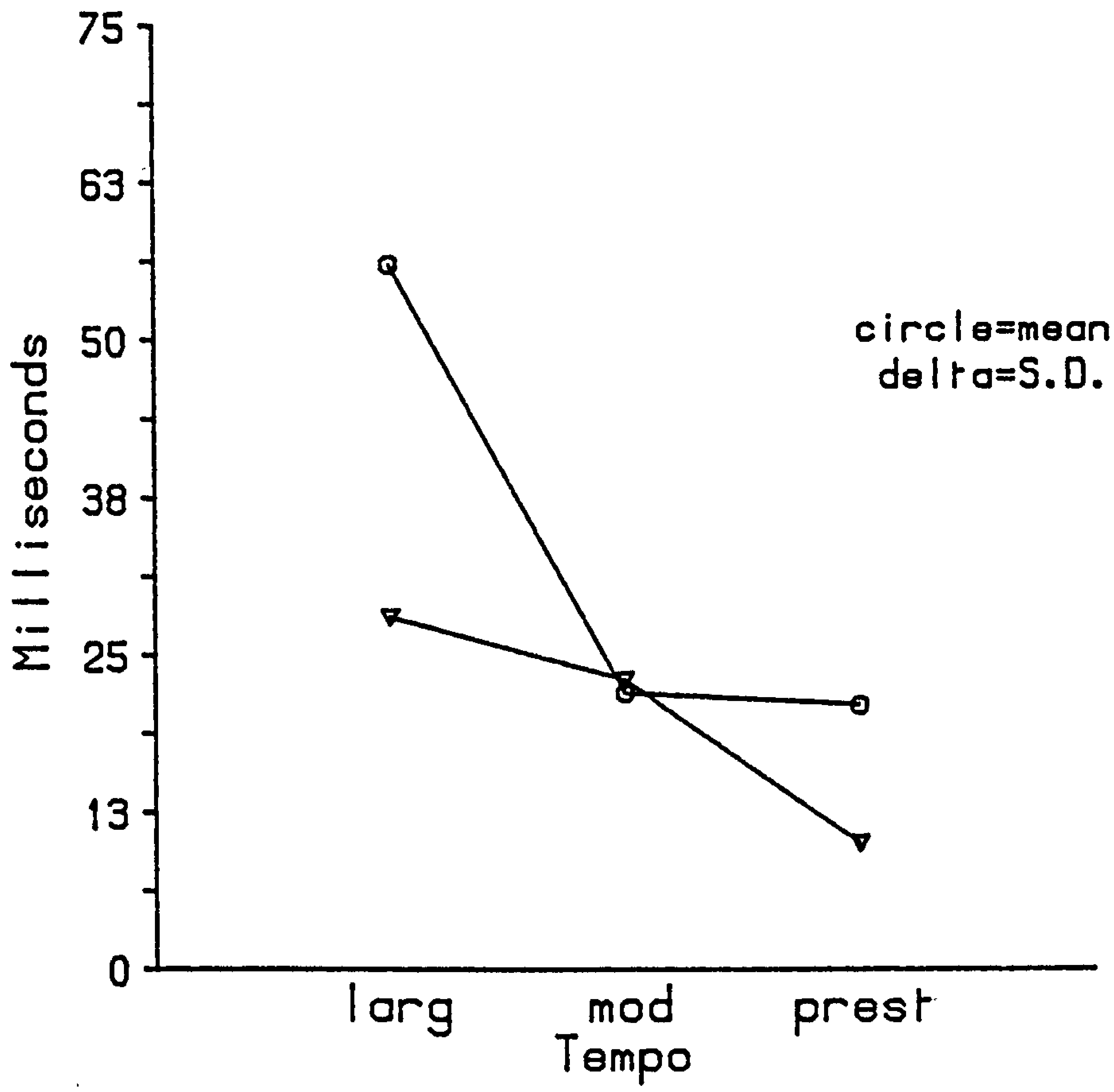
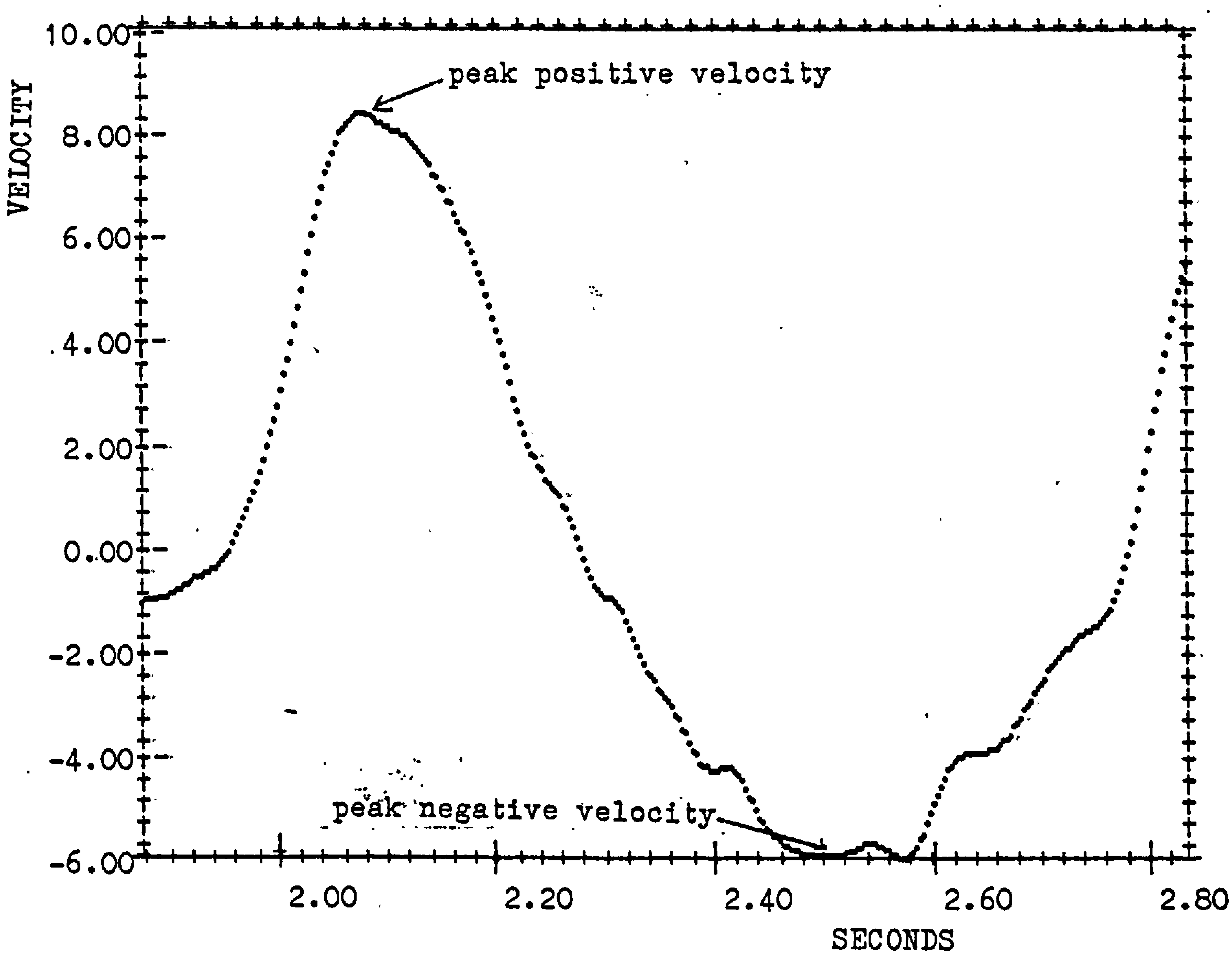


FIGURE 4.12 MEDIUM GRANDEUR,MODERATO



whether or not the transition points are involved in the synchronising process, the first step is to examine their location in the baton movement for internal consistency, the second step is to determine the degree to which phases of the drum action are tied to them.

Table thirteen shows the location of the peak negative velocity point in relation to the beat, and the location of the peak positive velocity point in relation to the top of the arc.

Table thirteen

Part 1: Baton peak(-) velocity-beat. Units are ms

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	449.8	305.7	64.6	353.7	271.1	96.3	376.4	284.9	46.0
S.D.	86.8	31.1	10.8	66.4	36.7	25.3	41.6	24.5	7.5

Part two: Baton peak(+) velocity-apex.

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	336.5	149.8	117.4	255.9	191.5	122.6	369.2	183.9	131.1
S.D.	53.4	29.5	12.1	54.5	8.8	12.7	53.0	22.1	15.2

In neither case is there any consistent variation by grandeur. In table fourteen the data is, therefore, presented by tempo.

Table fourteen

Part 1. Location of peak(-) in downbeat. Units are ms

	(a)Beat - Peak (-)		(b)Peak (-) - Top		
	Mean	S.D.	Mean	S.D.	Percent(a)/(b)
largh	393.3	50.2	302.6	30.9	130
moder	287.2	17.4	221.5	10.2	130
prest	68.9	25.4	204.2	13.3	34

Part two. Location of peak(+) in upbeat.

	(a)Top - Peak (+)		(b)Peak (+) - Start		
	Mean	S.D.	Mean	S.D.	Percent(a)/(b)
largh	320.5	58.3	290.0	61.2	111
moder	175.1	22.2	175.6	39.3	99
prest	123.7	6.9	68.3	17.2	181

The points to note are these:

(1) The S.D.'s of the times between the peak negative velocity and the beat are greater than those of the times between the top of the arc and the peak negative velocity. Therefore the peak negative velocity is, if anything, more closely tied to the top of the arc than it is to the beat. Similarly, the peak positive velocity is more closely tied to the top of the arc than it is to the beginning of the movement. Thus the peak positive and negative velocity points would serve as better indications of where the apex of the baton arc is to come or has been than where the beat is to come.

(2) As the tempo increases, the location of the peak negative velocity moves closer to the beat in absolute terms. However, its proportional location in the downbeat is similar (near the top) for larghetto and moderato, then jumps to the other end for prestissimo. The proportional location of the peak positive velocity is even more randomly located in the upbeat. Thus the peak velocities do not

occur at fixed proportions of the times allocated to the up and down phases.

If a given rate of braking (ROB) was to be preserved, then as the tempo increases and the time lag between, for example, the peak negative and the beat decreases, so the height above the baton beat position at which the peak negative is located should be reduced. To put this the other way round, there should be a clear decrease in the time lapse between the peak negative velocity point and the beat as grandeur decreases. There is no such trend. Therefore, at any given tempo, one is faced with a different and unrelated ROB as grandeur changes. This also precludes the peaks from serving as reliable drum action triggers.

(4) Without prior knowledge of the appropriate ROB, which one could have had if the peak negative point had occurred at a fixed proportion of the downbeat, one would obviously require to carefully monitor the ROB to extract the unique time to arrival in every trial. However, as the tempo increases, the duration of the period between the peak negative point and the baton beat reduces. It is only 68.9ms long, on average, at prestissimo. This is shorter than the average duration of the drummer's ballistic wrist action. This would clearly not allow any extrapolation from the ROB for the drummer to target a time before initiating the drum strike. Note, however, that accuracy on the beat at prestissimo is greater than at other tempi- precisely the opposite of what one would expect if a ROB strategy was being used.

(5) The period between the peak negative velocity point and the beat in fact only exceeds RT at larghetto. This means that the player could not be using these times as cues to the start of an action.

(6) Note, finally, that neither the drum beat nor the start of the drummer's wrist action are as closely tied to the baton peak negative velocity point as they are to the baton top, even though the time lapse between the top of the arc and the drum beat or the start of the wrist action is much greater than between the baton peak negative and the drum beat or the start of the wrist action. The figures for comparison are in table fifteen.

Table fifteen

Part one: Drum beat (DB) in relation to baton apex (BA) & peak negative (Bpk(-)). Units are ms

	DB-BA		DB-Bpk(-)	
	Mean	S.D.	Mean	S.D.
Tempo				
largh	657.9	93.6	353.7	116.2
moder	484.9	37.3	263.6	46.9
prest	251.7	25.5	47.2	23.5

Part two: Start wrist action (DSWA) in relation to baton apex & peak negative.

	DSWA-BA		DSWA-Bpk(-)	
	Mean	S.D.	Mean	S.D.
Tempo				
largh	574.7	95.2	270.5	122.5
moder	413.6	42.8	192.3	52.6
prest	189.5	23.9	-14.7	19.9

The time lapse from the baton peak negative point to the drum beat is only 41.8% (with an S.D. of 18.8%) of that from the baton apex to the drum beat, on average. The average S.D. of the times between the baton apex and the drum beat is only 81.8% (with an S.D.of 17.0%) of the average S.D. of the times between the baton peak negative and the drum beat. Thus the S.D.'s are generally smaller when the time lapses are all greater.

Thus we can dispose of the peak velocity points as candidates for either cues to the start of some drum action or as components in a ROB strategy.

Two possibilities remain. One is that some phase of the drum action is cued or triggered by a count, rather than by what the baton happens to be doing at the time. The other is that the drum action is targetted in advance towards a time derived from a schematic representation based on the preservation of the baton's temporal and physical proportions. It is harder to distinguish between these possibilities since, as with any movement of relatively fixed duration which occurs within the timespan of a longer movement, correlations of occurrence at beginnings of phases will inevitably be closely paralleled by correlations of occurrence at the ends of those phases.

However, there are some indications. It is unlikely that, for example, the wrist action is started after a simple count from the baton top, as the absolute time lapse varies so greatly by tempo. This would require memorising a time interval for each set of trials which could only be approximate.

A more plausible alternative was that the wrist action started at a time after the baton passed the apex given by the time taken by the baton to get to the apex (at time tBA) from the initiation of the upbeat (at time tBS), i.e. time tBA+(tBA-tBS), which would thus be specified within each trial.

Part one of table sixteen gives the actual average differences between the time taken by the baton to get to the apex from the initiation of the upbeat and the time taken to get to the beat from the apex. Part two of the table gives the average differences between the baton and the drum on the beat. Note that where these entries are negative, the drum came after the baton. Part three gives the average wrist action duration. Part four gives the addition of the values in parts three and two of the table, which gives the interval before the baton beat at which the wrist action started. Part five gives the subtraction of the values in part four from those in part one, which gives the difference between the point in time specified by the count and the actual start of the wrist action. The mean difference in part five is 9.7ms, the S.D. is 46.7ms.

Table sixteen

Part one: (tBB-tBA)-(tBA-tBS) differences. Units are ms

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	23.8	145.4	71.5	140.8	160.5	90.0	91.4	168.3	81.9

Part two: Baton-drum differences on beat

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	-37.8	-5.7	31.2	90.2	54.1	22.0	42.6	23.1	11.2

Part three: Wrist action duration

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	73.4	64.0	63.3	65.6	74.9	71.1	109.7	74.9	58.3

Part four: Time before baton beat at start of wrist action

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	35.6	58.3	94.5	155.8	129.0	93.1	152.3	98.0	69.5

Part five: Count time-start wrist action difference

Grandeur-	Small			Medium			Large		
Tempo-	Largh	Mod	Prest	Largh	Mod	Prest	Largh	Mod	Prest
Mean	-11.8	87.1	-23.0	-15.0	31.5	-3.1	-60.9	70.3	12.4

Note that the S.D. of asynchrony on the beat, over all conditions, is 36.3 ms, i.e. slightly smaller than the S.D. of the count time-start wrist action difference, whereas if the count time had triggered the wrist action we would expect the S.D. of the baton-drum difference on the beat to approximately equal the S.D. of the count location plus the S.D. of the wrist action duration. Furthermore, the differences in (five) do not vary in a coherent pattern by tempo or grandeur, whereas the baton-drum asynchrony on the beat does. This suggests that the location of the count time is more random than the location of the respective beats.

What remains, therefore, is that time to arrival is given, not by an absolute count, but by prior knowledge of the schematic proportions of the baton upbeat and downbeat in time and space. These proportions, as we have seen, remain constant over all tempi and grandeur. The top of the baton arc thus emerges as the critical fulcrum which demarcates the upbeat from the downbeat and thus defines the proportions. There is further evidence that supports this conclusion.

(1) Within every condition, a later than average start to the drummer's wrist action relative to the time at which the baton reached its apex is a good predictor of a late (where the drum comes after the baton) arrival on the beat. Similarly, an earlier than average start to the wrist action relative to the apex time indicates an early arrival of the drumstick, before the baton beat. A perfect relationship obtains in four conditions: at every tempo at the small grandeur, and at prestissimo at the medium grandeur. An average 62% relationship obtains in the other five conditions, giving an overall predictive validity of 78.9%.

(2) Subject's reports confirm the importance of the apex as a demarcation of phases. DR commented as follows.

> "The upbeat is crucial. There is most communication of tempo and time on the upbeat. And if the conductor is at all unsure then the muscles are going to be most tense by the time he gets to the top. If he pauses here at all,

instead of letting the baton peak and fall naturally, then its because he's tensed, he's nervous, he's trying to get his timing right."

Summary and Discussion

(1) The drummer controls the output volume required by controlling the terminal velocity on impact, which he does by holding the time of the critical ballistic wrist action constant and varying just one parameter, distance. He further reduces the degrees of freedom by starting from approximately the same position each time.

(2) The conductor communicates grandeur with the amplitude of the baton trajectory. The player's drum action thus models the baton action, scaled appropriately.

(3) The conductor communicates time by preserving the temporal and spatial proportions of the baton trajectory. Once this is established, this would allow, by constant monitoring, a derivation of the residual discrepancy between the observed and the schematic trajectories and launching of the drum action at the appropriate time.

(4) Synchrony on the beat is of the order found by Rasch.

(5) Not every phase of the drum action is coordinated with the baton. There is a approximate and a goal-directed phase which can be clearly demarcated.

(6) The only feature of the baton trajectory that approaches the degree to which the baton beat is synchronised with the drum is the apex of the movement.

(7) The apex is unlikely to be the trigger for a drum action, as the absolute time lag between the apex and the beat varies so greatly by tempo. Neither does it appear to figure in the derivation of a periodicity, as the times derived do not synchronise sufficiently systematically. Thus the significance of the apex is that it demarcates the phases of the baton trajectory, the proportions of which are the critical factors in the derivation of the start time.

(8) The rate of change model is not supported by the data. Neither is the discrete events and absolute intervals model, nor the cueing model. What remains is schematic representation and continuous monitoring. This means that the player must have some image of the baton trajectory that the conductor employs. The conductor in these experiments was surprised to find that his beat location was consistently below his rest position, so the planning of this action is obviously not entirely a conscious process. McElheren suggests that conductors practice by tapping a baton off a table. The feedback allows the conductor to aquire a more precise knowledge of where the beat is. The considerable degree of consistency that he achieved, however, indicates that this did not affect his precision adversely.

The trajectories employed by a particular conductor could be learned in rehearsal- although this is not rehearsed per se, it is implicit in every part of the rehearsal so there would be ample opportunity for a player to aquire a representation of the framework within which the conductor communicates his requirements. The existence of this process is borne out by the following statement from Premru (trombone, LSO)

> "Von Karajan did'nt seem to want anyone to play on the beat. Starting a quiet brass chord he always implied that he did'nt want to hear 'pah', he wanted the equivalent of an up-bow, the sound rising out of nothing...then with Klemperer, I think we always played behind the beat...he knew what he wanted and managed to convey it to us, and though we played behind the beat it worked. Now with Maazel and Muti, both very positive, I think we play on the beat. So much is intuition, very often one has to feel what to do. You tune in."

The essential arbitrariness of the definition of the trajectory could also be seen in the BBC2 series on the Tanglewood Music Centre, broadcast in 1985. Ozawa, the resident conductor, was seen to seize the arm of Gazon, one of the pupils, and move it through an ellipse to make him feel where the beats were, saying

> "Now the beat is at the top- now the top has moved over here" (about one-third of the way round the arc).

The books on conducting technique by Boult and McElheren contain schematic diagrams (copied in figures 4.1 and 4.2), which if followed would serve to reduce the varieties of pattern employed and thus promote clarity. The following quote from Rattle suggests that the conductor may deliberately construct a similar model for the guidance of action.

> "You have to run through the music in your mind and build up a picture of how you want it to sound...then when you are conducting you can constantly compare the image with what is going on, so that you know if you are wrong or not..if you did not review the music beforehand, it would be very difficult."

This is also borne out by an event that occurred during a conducting masterclass taken by Mehta. One pupil had mistakenly prepared a two and a three instead of a three and a two in one bar of Stravinsky's Rite of Spring. When corrected, he had great difficulty in reprogramming himself.

(9) The event targetting, not triggering, model is better able to account for what occurs at the first beat. The arguments in support of this are as follows. It has been demonstrated that there is only a small discrepancy between the conductor's beat and the percussionist's tap, averaging 25.7ms over all conditions. If there was an identifiable event in the baton action from which the drum action was triggered then we would expect to find an event to which the start of the drum action was as closely tied as the two actions are at the end of the action. After disposing of the peak velocity points, the only candidate left is the apex of the baton movement. The problem with the apex as a trigger is that the absolute time lapse between the baton apex and the start of the drum action could be quite large, up to 800ms at larghetto. As error would increase as a function of time, and given the very high degree of accuracy achieved at the end of the movements, it does not seem plausible that the start of the brief (72.8ms) drum action could be timed exclusively with respect to this particular event.

This does not mean that event-triggering could not be used to maintain the required synchrony or appropriate offset in the musical event. Gibson conducts on the "leading edge" of the beat, thus there is some time lag between his beat and where the orchestra are required to place their beat. It would be possible that event-triggering was an appropriate model to describe this technique, perhaps with Gibson's beat as the trigger. However, given that each instrumentalist's movement must take a certain time to prepare, especially on the first beat when they have the least information upon which they might base preparatory movements, the required movement preparation time will exceed the time lag duration. Thus it would be impossible that the orchestra would not anticipate the beat and make preparatory movements geared towards a time still implied, rather than waiting for the moment to arrive. Thus the orchestra could equally be targetting a time defined by Gibson, picking up and using advance cues as to the exact location, accent, and so forth, but with an offset.

If movement-targetting correctly describes the synchronisation on the first beat then it would be parsimonious if the same principle of targetting applied within the context of continuous beat-matching and the maintenance of a common action timing temporal structure in an ensemble. Otherwise, it would be necessary to postulate additional mechanisms when one would suffice. If successive event targetting describes what occurs generally, then the way in which the information is picked up and used at the outset should be similar to the way in which constant feedback is employed during the performance. The feedback is used to adjust the action aimed at the ensuing beat when that beat is redefined by the conductor (which can be within an upbeat) or when a discrepancy arises between the player's timing structure and that of the rest of the ensemble. The source of the information may be external, from the conductor or other musicians, or it may be from the musician's own internal clock. The medium may thus be visual, aural, or in terms of some abstract representation of time.

The musician's task could then best be described as having to actualize a given note sequence within a time span defined with respect to the ensuing and subsequent beats, initiating the note sequence before, and in a previously defined relationship to, the subsequent beat. Note that this analysis is applicable to both the instrumental style (beating the beats), and the choral style (beating every note), with the proviso that in the latter case the same process must apply for each individual note. It is helpful to make the distinction here between the beat and the rhythm. The conductor's job, according to both Monteux and Koussevitsky, is to give the beats and to let the players generate the notes between the beats and hence the rhythms.

The piece of music as a whole can be compared to a spatial array with the details of the array, for example, salient features and the distances between them, corresponding to "stepping stones" separated by different temporal "distances". The conductor indicates a series of prospective times-to-arrival which guide the rhythm with which the player "steps" through the array.

Chapter Five

Modelling the Musical Situation

Abstract

This chapter reviews the problem of developing an adaquate experimental procedure to model the complex timing operations of playing music. The principal questions dealt with in the next three chapters are then outlined, and those aspects of methodology in common to all three chapters are described.

Introduction

Is it possible to evolve a model of the processes involved in the making of music for the purposes of experimental manipulation and analysis? This general introduction to the next three chapters concerns the study of movement skills, and reviews the implications of the adoption of a reductionist psychology. The issue is the use of conventional laboratory methods of studying real activities through the use of simplified situations. No problem arises if the tapping experiments reported here are considered simply as tracking tasks. The difficulties arise when we wish to extend conclusions drawn from tapping experiments to real-life musical situations. To state the question more generally, in the study of tasks involving complex coordination, how far can we move away from the real skill in a pursuit of the controlled analysis of its properties? Is it in fact a question of degree? Shaffer (1981) lists possible directions of simplification:

(1) Start with a skilled performer and progressively simplify the real task. The problem is that at some point one loses touch with the skill and ends up studying an artifact. The safeguard is to keep comparing the performances in constrained and unconstrained conditions.

(2) Study relatively unskilled subjects in simple task paradigms. The question here is whether the characteristics of skill can be exhibited in such conditions. If the simulation is too simple it may be impossible to learn much about the real skill. For

example, Summers (1975) had subjects learn a cyclic tapping sequence on an eight-key array. In this situation, the subjects could hardly learn anything more than an associative structure, thus there cannot be a valid extension to the skills of typing or piano playing, for example, which entails the ability to generate new sequences to actualize previously unseen words and scores. Similarly, in linguistics, an alphabet-association task is not a basis for a model which purports to explain the generation of new utterances. Lashley (1951) reviewed this same problem in the context of speech comprehension, concluding that word arrangement was obviously not due to any direct associations, but to word meanings which are determined by relations of an altogether broader type.

The terms of Shaffer's theory of motor programming are as follows. The skilled performer has learned a large variety of procedures for translating intentions into actions. Thus the performer can assemble or plan representations of output which are an abstract organisation of the procedures that enable the deployment of the specific actions. This is similar to Chomsky's (1957) generative process model of linguistics.

This existence of a superordinate level of abstraction is evidenced also in the last minute preparations of a dancer or athlete, who mentally rehearses the correct sequence of moves, rather than the precise form of each move. Programming at this level would allow fluency in performance, as the basis for achieving coordinated timing could be set over a larger segment of the action.

The point of this is that this level of movement planning is achieved through experience, thus the naive subject given a simplified task cannot be expected to aquire the ability to plan in this way. Shaffer supports this argument by pointing out that those with a degree of musical skill are able to maintain independent concurrent tasks, such as playing polyrhythms where the hands must move to different and non-aliquot periodicities. A tabla player, for example, may interpose a non-aliquot drum break in a sixteen-beat space and resolve exactly on the sixteenth. There are even more demanding tasks facing the raga player. These are described in chapter one. This is arguably not a mere extension of bimanual actions with periodicities in an aliquot relationship, which most naive subjects could do, but a transcendence to a superordinate control of timing. Shaffer (1981) concluded that new principles of coordination arise in the aquisition of skill.

Thus a purely reductionist approach fails to provide an adaquate explanatory apparatus for the phenomenon of skilled movement. If skilled and fluid movement and its planning is more than the automation of a process of linkage of action elements, then it is the case that the laboratory study of unskilled subjects and their aquisition of associations of movements with different task elements cannot provide a comprehensive theory of skill. The key elements of generative flexibility, timing fluency, and expressive improvisation will not appear in that laboratory performance. If part of the process of skill aquisition is the evolution of new principles of coordination, then these will not be manifest.

Simplifications may, of course, be legitimately employed as tools to help in the conceptual separation of different processes involved in the aquisition, refinement, or use of skills. Blacking (1973), in a comparative study of Venda and European musical structures, demonstrates how certain culture-bound assumptions as to the nature of musical skill lead one to adopt an inappropriate methodology for the study of that skill. The point is that in order to avoid similar fallacies, it is necessary to keep clearly in mind potential dangers and limitations of the reductionist method. This may be done by maintaining contact with the original subject of inquiry, the skill as practiced in the world outside the laboratory. As Shaffer puts it, to compare the performances in constrained and unconstrained conditions.

The following three chapters are, methodologically, in the psychophysical or information processing tradition. Psychophysical data on the ability of subjects to detect discrepancies between auditory and visual signals was required to provide a measure of baseline response. This was required in order to be able to assess the achievement of temporal synchronies among musicians and between conductors and musicians.

However, the project was also a study in motor programming. Now, from an experiment of apparently simplified structure one cannot make the strong claim that the organisation of a sequence of responses at this level can entirely explain the organisation of skilled performance. To do so would be to fall into the reductionist fallacy. Clearly, however, insofar as elements of the experiment can be validly regarded as simplified but genuine elements of the real task, and with the provisio that all subjects possessed a genuine degree of skill in the real task, then it is possible to make careful extrapolations to the real world.

This is a weaker statement in positivistic terms, but it places a radically different emphasis on the significant candidates for study, pointing to the primacy of the holistic act, as opposed to conceptualised components of that act. We thus avoid the limitations of reductionism, although more care is needed in the interpretation of and generalisation from the results. As Capra (1982) puts it, in a discussion of neuroscience, it would seem that two complementary approaches are needed; a reductionist approach to understand the detailed neural mechanisms, and a holistic approach to understand the integration of these mechanisms into the functioning of the whole system.

General Project Description

There were two broad interrelated aims to these investigations. These were to study in more detail the means whereby a musician synchronises actions with those of a conductor or another player, and to investigate the microstructure of the musician's actions. A model task was devised that allowed manipulation of the information available to the player, and of the modes of the player's response.

The experimental variables.

Degree of asynchrony.

Here the subject had to make passive judgements of the degree of asynchrony between visual and auditory events. This was to measure the minimum detectable transmodal asynchrony, and to define the strategy adopted in achieving synchronisation. The subject was asked to make a judgement of synchrony a number of times in order to clarify exactly on what basis and at what level they were making the judgement. The parallel analysis in chapters three and four was the discussion of the phase of the conductor's baton action the players were defining as the beat and selecting as a target.

Production versus perception.

The subject had to make a series of active judgements of the asynchrony between target events and an output tap series. This was to investigate whether the addition of the production dimension adds, as Wing and Kristofferson (1973) suggest, an additional source of error.

Available information

The subject had to tap in time with a target series which could be presented in four different ways.

(1) Visual. The subject watched a disk revolving in front of him. Markers were fixed on the surface of the disk. As the disk spun, these markers would briefly coincide with a fixed marker directly ahead of the subject. The subject's task was to tap in synchrony with this visually presented series. The aim was to model the situation where a player in an orchestra has to produce a sequence of actions in time with the beats given by the conductor's baton.

(2) Auditory. The target series was a sequence of audible clicks. The subject sat with eyes closed, concentrating on the regular sounds, and used the same tapping device to produce a synchronized series. The aim was to model the situation where a player derives the beat-structure from the course of the music of the other players. There are times when the player must do this instead of, or in addition to, the visually presented cues from the conductor.

(3) Both. In this condition both visual and auditory sources of information were present, as they normally are in the real-life situation.

In one experimental subset the sources of information were synchronized at the outset to observe whether the extra richness of the information from two available dimensions would make the task easier or more complex for the subject. In the matched subset, the sources of information were offset to determine whether the subject actually had an effective preference.

(4) No target. Here the player attempted to replicate the tempo of the target series to which he had just been exposed, without any further information being present. The aim here was to see how long the player could maintain a regular output without constant reference to an external cue source, and the degree to which they suceeded in replicating a previously experienced tempo.

The general aim was to discover how accurately and consistently the player could entrain his production series with the target series in the above conditions. In order to determine whether any one information-bearing dimension could effectively provide the player with more accurate information, in that it could be more readily picked up or incorporated into the player's action timing, it was necessary to isolate the possible dimensions and observe performance in each. This analysis is parallel to the analysis described in chapter two which compared between the visual information from the conductor and the auditory information from the rest of the orchestra.

Grouping

The player was presented throughout this entire experimental project with mechanical isochronic target series. In the real musical situation, production and perception is arguably beat-based. It was therefore necessary to consider possible evidence for this. This was done by determining whether the subject, given an isochronic sequence, would produce an isochronic series or impose a beat-based production strategy. Possible compounding variables were investigated in addition in order to ensure that the unit of the beat could be self-selected rather than imposed by situational constraints.

Tempo

All production conditions were cross-matched with a range of tempi in order to observe whether different strategies had perforce to be adopted when the task had to be performed at different speeds, and to investigate the relationship between tempo and accuracy.

Cross-matching of experimental variables.

The cross-matching is summarized in table one:

Table one

Variable	Tempo	Prod.	Perc.	Cond.	Group.
Tempo	-	Yes	Yes	Yes	No
Production	Yes	-	Yes	Yes	Yes
Perception	Yes	Yes	-	Yes	N.A.
Conditions	Yes	Yes	Yes	-	Yes
Grouping	No	Yes	N.A.	Yes	-

General Methods

As with the first three experimental chapters, the details of the methods employed are given in each of the following three chapters. There are, however, certain features which are in common to the experiments described in these chapters (six to eight). These are set out below.

Apparatus

Subjects sat on a stool 48cm tall. They sat squarely at a table 75cm high. Directly in front of them was a disk, 26.5cm in diameter, mounted horizontally with its top surface 26cm above the table. The eye level of the subject was 23cm above the disk, and 41cm removed from the midpoint of the disk in the horizontal plane.

Disk markers

Affixed to the disk were four 6x6mm squares of a matt black material, each set at right angles to the direction of motion and with its centre 27. 5mm in from the rim. They were equally spaced around the circumference. Passing through the leading edge of each square were 35x1mm rectangles of the same matt black material, each lying on a radius separated by 90 degrees from the others and terminating at the rim of the disk. Thus 4.5mm of the 35x1mm rectangles protruded directly towards the disk centre beyond the inner edge of the 6x6mm squares.

The 35x1mm rectangles, which will be referred to hereafter as markers, were set as the subject's targets. The 6x6mm squares were required to operate a light-gate which registered their passing as the disk revolved. At the maximum speed required of the disk (44.1 rev:min) a square of side 6mm passed under the light-gate in 12.4ms which was approximately the minimum transition duration which could be registered. The 12.4ms was 3.6% of the IBI At the minimum speed (12.5 rev:min) the square passed under the gate in 43.6ms which of course is also 3.6% of that IBI

Light-gate register

The light-gate was a light-activated switch (LAS) of type R.S. 307-313 incorporating a photodarlington sensor and light-emitting diode (LED). The LAS was mounted permanently to the side of the same structure that supported the disk with the motor that powered it. The surface of the disk was light coloured to reflect the light from the LED but matt to avoid excess light scatter. The LAS registered a transition when the black matt marker and square passed underneath and the LED emissions were absorbed and no longer reflected. A second transition was recorded as the light-absorbent surface moved out from under the LAS. The time of occurrence of each transition was recorded.

Fixed marker

A thin silver wire of 0.2mm diameter gauge was fixed down the midline of the side of the LAS facing the subject. The system was calibrated so that as the marker passed directly underneath the silver wire, the LAS tripped. The base of the silver wire was set 3.3cm from the rim of the disk.

Tap-switch and Tap-plate

Under some experimental conditions, the subject was required to make a physical response to indicate a judgement of the moment of coincidence between the markers. In these conditions, the subject was given a purpose-built switch to operate. This switch had two main components, a tap-switch and a tap-plate. The tap-switch was 22cm long and weighed 16.3gm. The handle, which comprised 72% of its length, was plastic. The tip was copper. The tap-switch was light, rigid, and easily held and controlled with the subject's preferred hand. The tap-plate was a 9cm x 24cm brass plate. This was firmly clamped to the table surface with a sandwich of compressed padding underneath to absorb vibration. The plate was set within easy reach of the subject, on the side of their preferred hand, so that they could be confident of its whereabouts without having to move their direction of gaze from the fixed marker and the disk.

When the tap-switch made contact with the plate, a circuit was completed (see circuit diagram, appendix five). The time of this event was recorded, as was the time at which contact was subsequently broken.

Sound pulse generating and timing equipment

Under other conditions, subjects were asked to make a judgement of the degree of match or mismatch between an auditory event and a visual event. The visual event was the coincidence of the markers. The auditory event was a sharp click, obtained by chopping a 1 hz signal into pulses of 2ms duration. In order that a genuine synchrony be obtainable, each operation of the pulse-generating system was triggered by the LAS. The "auditory system" comprised (1) two Grass S8 stimulators, the first being employed as a means of controlling a variable delay, the second as a pulse generator; (2) a transformer of type R. S. Hygrade Fil. Trans. HWG to step-down the output from the second stimulator; and (3) a 20mw 8 ohm loudspeaker. This auditory system required a finite time to operate from initial triggering to the output of the pulse. Therefore the subject was asked to tap to or otherwise judge the coincidence of the auditory event with a lining-up of markers that was immediately subsequent to that coincidence that had actually triggered the auditory system. The speaker was approximately 0.5 metre distant from the subject, so the sound arrived at his ear in less than 2ms.

Signal Intensities

Following Bartlett and Bartlett's (1959) finding in a similar experimental situation that signal intensity did not affect performance (given that intensity was above the limen of perception), the signal intensity was not varied.

Disk and disk drive

The disk was directly driven by a Bodine NSH-33R linear electric motor. Disk speed varied slightly. The extent of this problem was as follows. In fifteen trials of one hundred and fifty events (in this case, marker coincidences), the mean (over the fifteen trials) S.D. was 4.2ms. Implications of this problem are discussed in chapter seven. This variation was kept to a minimum by running the motor and all other apparatus for thirty minutes before recording.

Effect of error on statistical assumptions

The application of covariance analysis to time series assumes the series to be stationary. In the experiments reported in this paper, the target series was arbitrarily set, but there was a slight degree of error. It is assumed that this error was not significant and that in effect the target series was stationary. The effects of error variance in the target series are discussed in chapters seven and eight.

Rotation speeds

The disk was run at five speeds. These are given in table two.

Table two

	Rev/min	Markers/min	Event interval	Tempo
(1)	12.5	50.0	1.200	larghetto
(2)	15.2	60.9	0.985	andante
(3)	19.5	78.0	0.769	moderato
(4)	27.0	108.1	0.555	allegretto
(5)	44.1	176.5	0.340	prestissimo

Control of subject's position

Aiba (1977) found that an estimate of time to arrival of a luminous spot moving in the fronto-parallel plane depended not only on the actual time duration but also on the physical distance involved. Although Aiba makes no mention of any physical restrictions on his subjects, there remained a possibility that an increased distance between the subject's eyes and the markers which coincide in the horizontal plane might give rise to some systematic change in the accuracy with which physical distance in the fronto-parallel was assessed, as it systematically decreases the distal stimulus in terms of visual angle subtended, and might thereby affect judgements of time-to-coincidence. Furthermore, movement of the subject's head transverse to the true marker coincidence plane would result in a parallax shift and a consequent change in the apparent location of the marker coincidence point.

In brief, the exact orientation and location of the subject's head could affect the judgement of the moment of coincidence between the disk markers and the fixed marker. To control for this, a "window" was built out of 12mm diameter tubeframe. The inside dimensions of this window were 10cm x 10cm. It was supported by a stand, with its bottom outside edge at a fixed height above the table. This height could be varied for subjects of different heights, with the sole criterion that the subject's line of sight, once they were comfortably seated and settled, should pass through the centre of the space defined by the window frame. Thus for a subject of height 1.7 meters, the window was set 35cm above the surface of the table. The distance from the fixed marker to the lower inside edge of the window was, in the case of this example, 40cm. The distance from the fixed marker to the centre of the stand was kept constant at 36cm.

This arrangement almost entirely removed the subjects' freedom to set their heads at different angles to the fixed marker. They were still free to move their heads in the saggital plane, but were generally observed to do so with a total latitude of only 10cm approximately. Each subject's eyes could be judged to be within a range of 47cm to 57cm distance from the fixed marker, and to remain within that range in a relatively fixed and invariant manner without having to resort to any further restrictive intrusions.

The subject's position and every aspect of the apparatus are shown by photographs 5.1 and 5.2 in appendix two.

Event sequencing and recording

Event sequence

A schedule of events would run as follows.

(1) The LAS would trip as the first marker passed underneath.

(2) The LAS signal, in addition to being recorded, would trip a R. S. Reed relay.

(3) The relay would trigger the first stimulator.

(4) After a delay, which could be adjusted by the subject, the first stimulator would trigger the second stimulator.

(5) The second stimulator would emit a 2ms pulse to the loudspeaker. The time of this event would also be recorded.

(6) The subject would hear the sound emerge approximately coincident with the passage of the next marker under the LAS.

The subject could then adjust the delay until the synchrony of auditory and visual events seemed exact to them.

The relevant circuit diagrams are shown in appendix six.

Event Recording

Times of all signal transitions were monitored. There were three signal channels:one for the tap-switch, one for the LAS, and one for the sound generator. Each was monitored, via an analogue to digital (A-D) converter, by a DEC PDP11 minicomputer. Each channel had independently set signal limen to filter out noise. The A-D converter operated over a 10 volt range, from -5 to +5 volts. All signals operated in the positive range only, from 0 to 5 volts.

Channel one was assigned as the tap-switch channel. It operated over the full 5 volt range. With the tap-switch*tap-plate contact open, it registered 0 volts. With the contact closed, it registered +5 volts.

Channel two was the LAS channel. It operated over a 2 volt range, from +2 volts (contact closed) to +4 volts (contact open, i.e. when a non-reflecting marker passed under the LAS and broke the circuit).

Channel three was the signal generator channel. It operated over a 3 volt range, from 0 volts to +3 volts.

The limen were set at 3.5 volts (channel one), 2.5 volts (channel two), and 1.5 volts (channel three). As the signal made a transition past the threshold value, in either direction, a clock-referenced time and a linked channel code were stored in an array. This sequence could then be displayed in time-series format. The real-time event recording programme and principal subroutine are listed in appendix five.

The tap-switch channel was used for two purposes. The first was to record the subject's output. The second was to signal the start of a recording series. After the recording programme had been started, the subject chose the moment they wished to start tapping, whether there was a target series present or the player was in an isolation condition, and touched the tap-switch to the tap-plate for a minimum of one second. This extended contact closure triggered the start of a recording. As soon as the contact was broken again, transition times on all three channels were stored.

In the active sessions, where the subject was using the tap-switch to tap along with a target series, the experimenter would keep track of the number of tap-switch transitions recorded. It was not desirable that the subject should keep track of this number, in case the sub-vocal or mental tallying should introduce an artificial cadence and affect the output. When the number of events (half the number of transitions) reached one hundred and fifty, the experimenter called a halt.

The subject then stopped the recording by again touching the tap-switch to the tap-plate for a minimum of one second.

This of course meant that recordings could contain data points from either the visual or the auditory target series, which actually occurred either between when the subject broke the series-initiating contact and when they made their first targetted tap, or between the last targetted tap and the closure of the series-terminating contact for one second. These data points were easily identified, as subtraction of the tap-target series resulted in a series which had been displaced by one or more IBI's if the wrong points were used, and subsequently removed.

Correction procedure for subject error

Subjects occasionally missed a beat, leaving a single gap in an otherwise good recording. These missing points were filled by a value averaged from adjacent points.

Sometimes the tap switch was operated too vigorously and rattled on the plate, giving a spurious data entry. These bounces were eliminated, the smaller IBI being invariably sufficient to determine which was the 'real' tap and which the 'bounce'.

A maximum of two errors of either type over the one hundred and fifty taps was accepted, if there were more the series was re-recorded.

Subjects

This entire experimental series was recorded primarily with one subject. A second subject was employed to replicate the key conditions. Both were, of course, experienced musicians. The relevant biographical details are given in appendix four.

Chapter Six

Visual-Auditory Synchronization

Abstract

In order to be able to define the target phase of a continuous motion, with which a musician must synchronise (see chapters three and four), it is necessary to have an estimate of the extent to which he is able to detect discrepancies between the target and the outcome of his actions. A task was devised which modelled the musician's problem. Subjects had to coordinate a sound with a visual event (which represented the baton beat). What is clearly demonstrated is the application of a two-stage strategy, even in this artificial task. The first stage is to select an offset between the auditory and visual events. The second stage is to replicate that offset. It is suggested that this genuinely reflects the process of achievement of coordination between conductors and musicians.

Introduction

This chapter deals with two interrelated questions. These are as follows.

The first question concerns the limits of a musician's ability to detect an asynchrony between a visual and an auditory event. This datum is needed in order to be able to qualify the degree of synchrony achieved by the musician, who must engage in a course of action such that a note sounds at a time synchronised with a visual event given either in the trajectory of the conductor's baton or in some other way, such as a nod, foot-tap, armwave etcetera. One of the findings described in chapter four was that musicians could synchronise their actions with a visual event to within 25.7ms, on average, with a S.D. of 39.6ms.. It became obvious during that study that it was necessary to define the exact event in the trajectory with which the player was attempting to synchronise. The experimental determination of that definition is described in chapter three. In the course of that investigation, it became necessary to have an independent measure of the degree of accuracy with which the player could synchronise a visual and an auditory event in order to ascertain the error factor which might be expected to obtain around any given point in the trajectory, thus making it possible to make a distinction between candidates for the visual event which the musician might select as targets for the production of a synchronised auditory event.

On a more fundamental level, it is also of intrinsic interest to ascertain the limen of perceptability of asynchrony of transmodal events. Michon (1967) agrees with Hirsch and Sherrick (1961) that with an asynchrony between two auditory events of less than 25ms the order of the events cannot be determined. Green (1971) has found that the limits of temporal resolution with auditory events is as low as 2ms with transients. Leshowitz (1971) found that if a section of a 50ms long continuous sound was reversed it could be detected, even when the section length was reduced to 5ms. Would a visual-auditory asynchrony be more or less obvious? Efron (1963) and Hirsch and Sherrick suggest that the detection of simultaneity depends on lateralisation, as the comparison occurs in the hemisphere dominant for language. If auditory stimuli are presented at each ear, the detectable discrepancy may be as low as 3 or 4ms. Halliday and Mingay (1964) noted that the process of comparison apparently makes allowance for the non-equidistance of conduction pathways. McGurk and McDonald (1976) and Dixon and Spitz (1980) have investigated transmodal asynchronies. McGurk and McDonald note that speech asynchronies may be a special case, as tolerance for visual and auditory asynchronies is lower with speech than with non-linguistic sound sources. Dixon and Spitz have confirmed this experimentally.

Finally, it was necessary to establish whether all the operations involved in an apparently psychophysical task of this kind can in fact be described at the implied "low" level, or whether it is invariably necessary to include superordinate or "higher" level considerations in the explanation of the results. A similar problem is considered in chapter seven.

The second question is a development of the first question. With a visual-auditory synchronisation study, repeated over different tempi and replicated at a given tempo, it is immediately possible to see whether the subject achieves the same degree and direction of asynchrony in similar conditions, and whether the selection of asynchrony is systematically affected by tempo. This provides information about the strategy adopted by the subject in making the relevant decisions, the cues used to determine what constitutes an acceptable degree of synchrony, and at what level this strategy can be considered to be invariant.

Methods

The subject observed the disk through a tubeframe "window". The markers on the disk triggered the stimulator. A variable length delay could be introduced between the triggering marker and the click produced by the stimulator. Each trial (there were five) in a set was started with this delay set to a value of approximately one-third of the inter-beat-interval. This resulted in an obvious discrepancy between the coincidence of the markers on the disk and the fixed marker on the one hand and the click on the other. The experimenter then slowly reduced the delay by rotating the control dial at a constant speed. When the subject perceived a synchrony between the coincidence of the markers and the click, they called a halt. The subject was then allowed to request any subtle adjustments that they felt necessary. There was no pressure of time on the subject. When they felt certain that they had set the two events to within the limits of their ability to detect simultaneity, a recording was made. Ten points were recorded. The time series of click-events was then subtracted from the time series of marker-events. The ten points were then averaged. The means were used in the analysis.

With the principal subject, A.M., there were five trials recorded at each of four tempi : allegretto, moderato, andante, and larghetto. There were also fifteen trials (in three blocks of five) recorded at prestissimo. The latter was done to observe whether the subject would necessarily select the same offset in an identical condition on a different day. In every other case, trials for any one tempo were recorded sequentially. On any given day, one or two complete sets of data were recorded. Details of the tempi are given in table one.

With the second subject, T.S., replications were run only at the extreme and mid-range tempi: prestissimo, larghetto, and moderato. As with the first subject, two additional blocks of five trials were recorded at prestissimo. The number of tempi were reduced because it was only necessary to show, if any directional tempo-linked effect obtained with the first subject, that the effect and its directionality would also obtain with another subject. The additional blocks of trials at prestissimo were necessary in order to see whether the existence and extent of inter-block variation in event location were a general phenomenon, or specific to the first subject.

All values, in tables and figures, are in ms.

Table one

The range of Tempi employed

Tempo	Beats:min	Inter-beat interval
prestissimo	176	340 (ms)
allegretto	108	555 (ms)
moderato	78	769 (ms)
andante	61	985 (ms)
larghetto	50	1200 (ms)

Results

Tables two and four contain the visual- auditory series offsets that were perceived as synchronous by subjects A.M. and T.S. respectively. The actual offsets selected are given, as it is necessary to discuss some of them individually. Tables three and five contain the means and S.D.'s within the conditions for the two subjects.

Table two

Subject A.M. - Series offsets perceived as synchronous

Tempo	Offset
[prestissimo]	
Set 1	
Trial 1	126.9
Trial 2	126.7
Trial 3	125.2
Trial 4	127.3
Trial 5	127.1
Set 2	
Trial 1	-17.0
Trial 2	31.0
Trial 3	25.6
Trial 4	32.0
Trial 5	41.5
Set 3	
Trial 1	46.9
Trial 2	49.6
Trial 3	48.7
Trial 4	49.7
Trial 5	46.2

[allegretto]

Trial 1	-60.5
Trial 2	-54.5
Trial 3	-37.3
Trial 4	-44.2
Trial 5	-41.3

[moderato]

Trial 1	-29.0
Trial 2	-23.6
Trial 3	-26.0
Trial 4	-30.6
Trial 6	-35.4
Trial 5	-15.0

[andante]

Trial 1	-58.0
Trial 2	-37.5
Trial 3	-30.0
Trial 4	-34.5
Trial 5	-15.6

[larghetto]

Trial 1	-46.9
Trial 2	-48.9
Trial 3	-64.4
Trial 4	-74.6
Trial 5	-61.0

Table three

Subject A.M. - Mean and S.D. of Offsets

Tempo(set)	N	Max Val	Min Val	Mean	S.D.	Mean as % IBI
prestissimo(1)	5	127.3	125.2	126.6	0.8	37.2
" (2)	4	41.5	25.6	32.5	6.6	9.6
" (2)	5	41.5	-17.0	22.6	22.9	6.7
" (3)	5	49.7	46.2	48.2	1.6	14.2
allegretto	4	-54.5	-37.3	-44.3	7.4	8.0
"	5	-60.5	-37.3	-47.6	9.7	8.6
moderato	5	-35.4	-23.6	-28.9	4.5	3.8
"	6	-35.4	-15.0	-26.6	7.0	3.5
andante	4	-58.0	-30.0	-29.4	9.7	3.0
"	5	-58.0	-15.6	-35.1	15.3	3.6
larghetto	5	-74.6	-46.9	-59.2	11.5	4.9

Comments on Table three: In each case where two N-values are given, the lower figure refers to the set of data after the most anomalous trial is removed. For example, in prestissimo, set 2, N=4, trial 1 has been removed. It is distinctly out of the range of the others, as the direction of the visual-auditory asynchrony was reversed. That means that in that one trial the subject set the auditory event to occur after the visual event, when it was more usually set to occur before the visual event.

Table four

Subject T.S. - Series offsets perceived as synchronous

Tempo	Offset
[prestissimo]	
Set 1	
Trial 1	101.6
Trial 2	89.6
Trial 3	78.5
Trial 4	97.1
Trial 5	88.9
Set 2	
Trial 1	45.8
Trial 2	67.5
Trial 3	49.0
Trial 4	57.5
Trial 5	54.8
Set 3	
Trial 1	101.7
Trial 2	101.7
Trial 3	85.8
Trial 4	87.3
Trial 5	87.8
[moderato]	
Trail 1	104.6
Trail 2	107.1
Trail 3	104.7
Trail 4	107.6
Trail 5	108.2
[larghetto]	
Trial 1	70.8
Trial 2	71.2
Trial 3	74.8
Trial 4	84.0
Trial 5	84.2

Table five

Subject T.S. - Mean and S.D. of Offsets

Tempo(set)	N	Max Val	Min Val	Mean	S.D.	Mean as % IBI
prestissimo(1)	5	101.6	78.5	91.1	8.8	26.8
" (2)	5	67.5	45.8	54.9	8.4	16.2
" (3)	5	101.7	85.8	92.9	8.1	27.3
" (3)	2	101.7	101.7	101.7	0.0	29.9
" (3)	3	87.8	85.8	87.0	1.0	25.6
moderato	5	108.2	104.6	106.4	1.7	13.8
larghetto	5	84.2	70.8	77.0	6.7	6.4

Comments on Table five: In prestissimo (3), three N-values are given. The first figure refers to all five trials. The second and third figures are subdivisions of the trials into the first and second, and the third, fourth, and fifth. This was done because the subject appears to have changed the offset at this point. This is discussed fully in the text.

Analysis of results

Part one: What is the invariant ?

First consider the question of discriminability of asynchronies.

Take subject A.M. first. The largest mean offset observed with A.M. was 126.6ms (37.2% IBI), in the prestissimo condition. This was approximately equal to the initial offset before the subject started to adjust the delay. The smallest mean offset achieved was -28.9ms (3.8% IBI) in the moderato condition. The smallest proportional offset obtained was -29.4ms (3.0% IBI) in the andante condition. The latter two are certainly more of an order with Michon's figure of 25ms, but this finding is apparently complicated by the observation that in the first condition mentioned he obtained the tightest grouping of the entire series!

That is, the subject set the visual and auditory events so far apart that they are about one third of a cycle out of phase, but could then return over five trials to set them in precisely the same relationship to each other- with a S.D. of only 0.8ms and a total range of only 2.1ms.

This finding was the first hint that while the absolute size of the offset appears to vary widely and quite arbitrarily, some factor was indeed being held remarkably constant- to a degree approximately thirty times finer than that found by Hirsch and Sherrick. Even in the trial block with the most variation (larghetto), a S.D. of

11.5ms (total range 27.7ms) was obtained. Now consider subject T.S.'s data. Within each block there is a high degree of consistency. The tightest cluster is at moderato, with an S.D. of only 1.7ms. This is followed by larghetto, at 6.7ms, with the three prestissimo blocks averaging 8.4 ms with an S.D. of 0.4ms (taking the third block as a whole).

The largest mean offset with T.S. is 106.4ms, but here it obtains at moderato. This is 13.8%, almost one-seventh, of the IBI. So the offset here has been reduced to just under half the start position value. Yet here too, just as with the first block of trials at prestissimo for subject A.M., the tightest grouping is obtained- a S.D. of only 1.7ms over five attempts. It is noticeable that with both subjects the smallest S.D.'s obtain with the largest mean offsets, but this must be coincidental, as the tempi selected are not the same. What it does confirm is that absolute offset size is not the critical variable in judgements of synchrony.

T.S.'s data also confirms that while the offsets selected vary widely, and are from significantly different populations, there is some way in which the selection of these offsets is being very precisely controlled. This is demonstrated by the very narrow distributions of the offsets within sets.

Tables three and five are illustrated in figures 6.1 and 6.2 respectively.

Figure 6.1
Selected offsets
Means and two S.D.'s
Subject A.M.

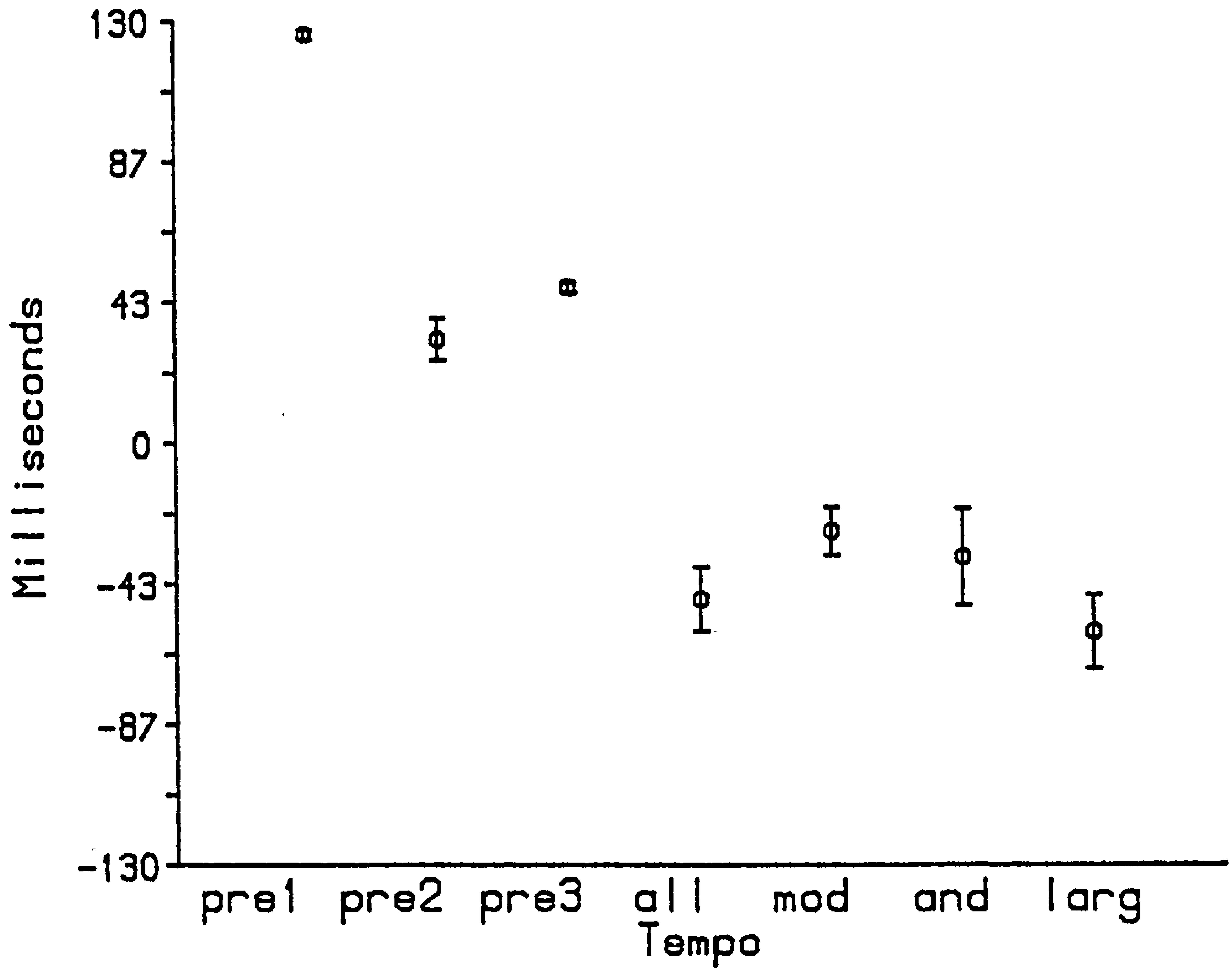
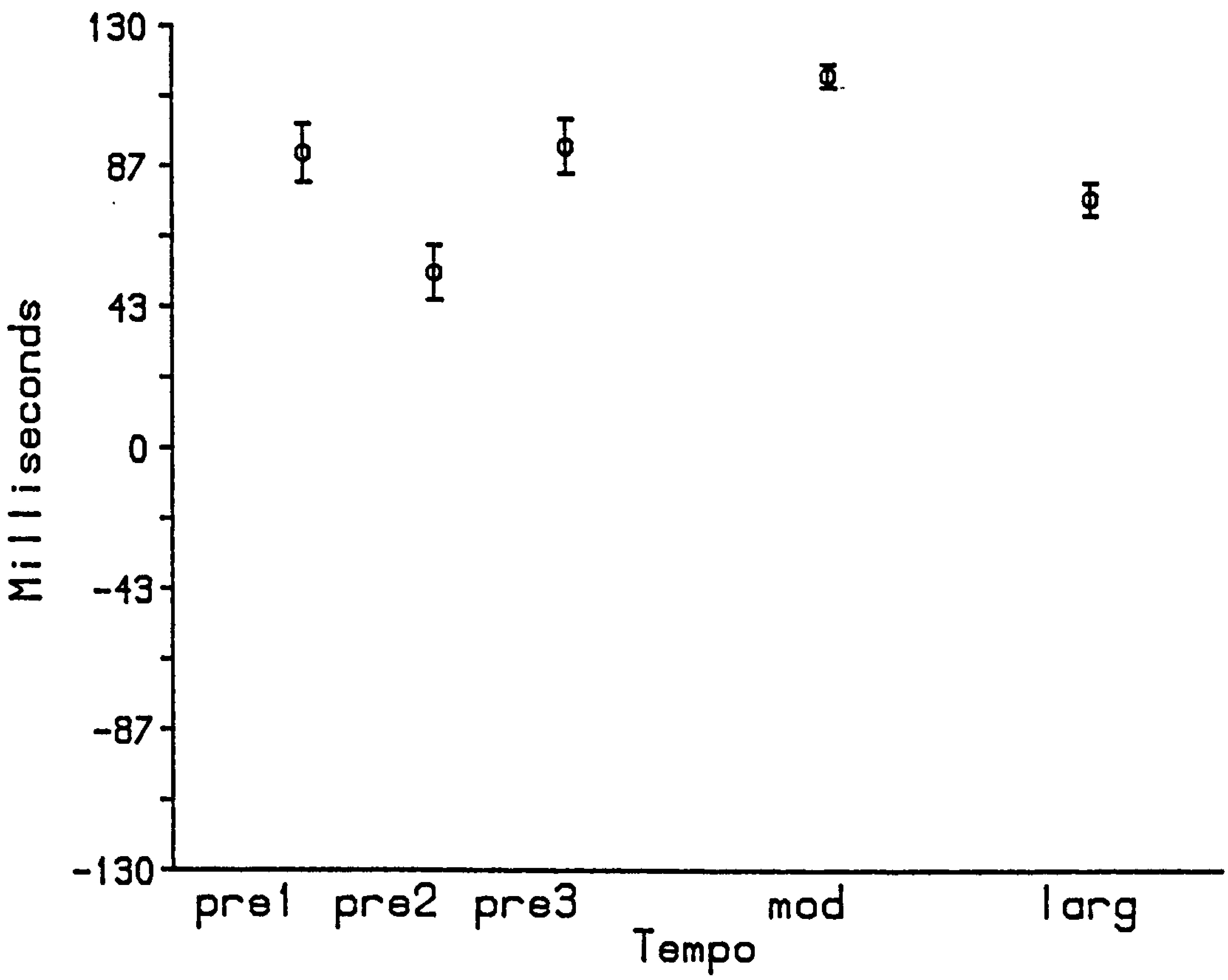


Figure 6.2
Selected offsets
Means and two S.D.'s
Subject T.S.



Effect of Tempo

The next point to establish was whether there was any evidence that either the offset chosen expressed as a percentage of the IBI, or the S.D. of a block of five trials, varied systematically by tempo. There was, for each of these, some suggestion of orderly sequencing by both subjects. Here are the figures again with their ranks in brackets. All the real values are means, in ms.

Table six

Subject A.M. - Ranked S.D.'s and IBI Percentages

Tempo >	prestissimo	allegretto	moderato	andante	larghetto
% of IBI->	37.2 (5)	8.0 (4)	3.8 (2)	3.0 (1)	4.9 (3)
S.D.->	0.8 (1)	7.4 (3)	4.5 (2)	9.7 (4)	11.5 (5)

Table seven

Subject T.S. - Ranked S.D.'s and IBI Percentages

Tempo >	prestissimo	moderato	larghetto
% of IBI->	26.8 (3)	13.8 (2)	6.4 (1)
S.D.->	8.8 (3)	1.7 (1)	6.7 (2)

Table eight

Subject T.S. - Ranked S.D.'s and IBI Percentages

[Block 3 at prestissimo subdivided]

Tempo >	prestissimo	moderato	larghetto
% of IBI->	26.8 (3)	13.8 (2)	6.4 (1)
S.D.->	0.0 or 1.0 (1)	1.7 (2)	6.7 (3)

Take A.M. first. With the S.D.'s, the only non-linearity is the transposition of the second and third places, with the percentages the non-linearity is more serious with the third rank being displaced through two positions.

Now consider T.S.'s data. Perfect linearity is obtained with the percentages- in table seven we see the S.D. ranking is disrupted by the prestissimo figure, which is at the "wrong" end of the ranked series. However, for reasons given in full later, this figure may be too coarse. If the third block at prestissimo is subdivided by offset, and the two sets of offsets selected taken to constitute sub-blocks of trials, and we then use the S.D.'s of these sub-blocks in the comparisons with the S.D.'s achieved at other tempi, perfect linearity is achieved in the tempo- S.D. size relationship. This is shown in table eight.

Tables six, seven, and eight are illustrated in figures 6.3, 6.4, and 6.5.

Statistical test

Is the linearity significant? There is some dispute in the literature as to how to assign significance to degrees of nonlinearity in ranks. A number of authors- Wilcoxon (1945), Festinger (1946), Mann and Whitney (1947), and Whitney (1951) have offered versions of tests based on ranks which are in some way analogous to the usual ANOVA procedures. The Kruskal and Wallis (1952) test subsumes the key elements of those aforementioned tests, but still does not specifically take as alternative to the null hypothesis a hypothesis that the populations from which the samples are drawn are stochastically ordered. Thus it was necessary to adopt the Jonckheere (1954) test against ordered alternatives. Some

Figure 6.3
Mean offsets as IBI percentages
and S.D.'s, against tempo
Subject A.M.

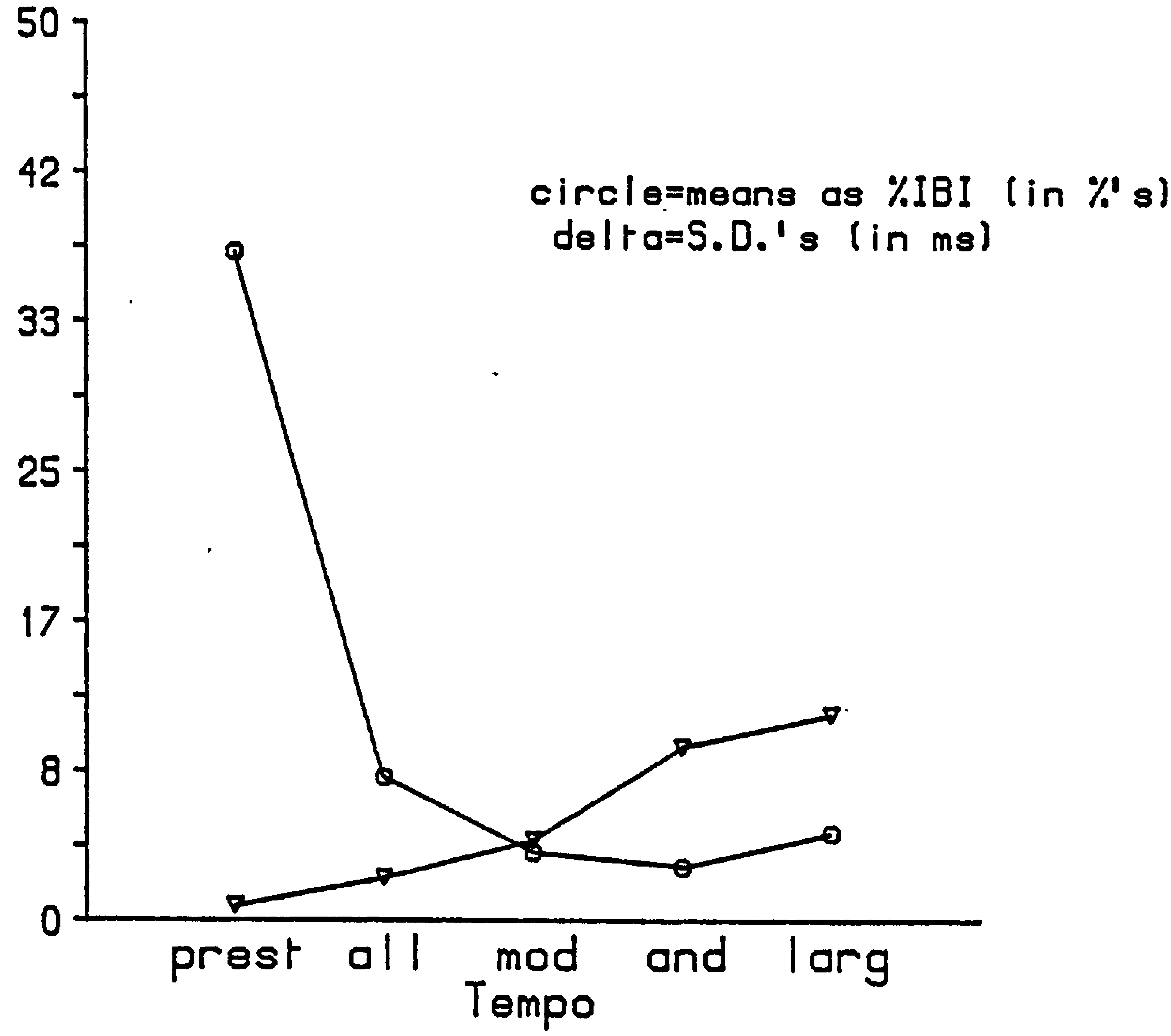


Figure 6.4
Mean offsets as IBI percentages
and S.D.'s, against tempo
Subject T.S.

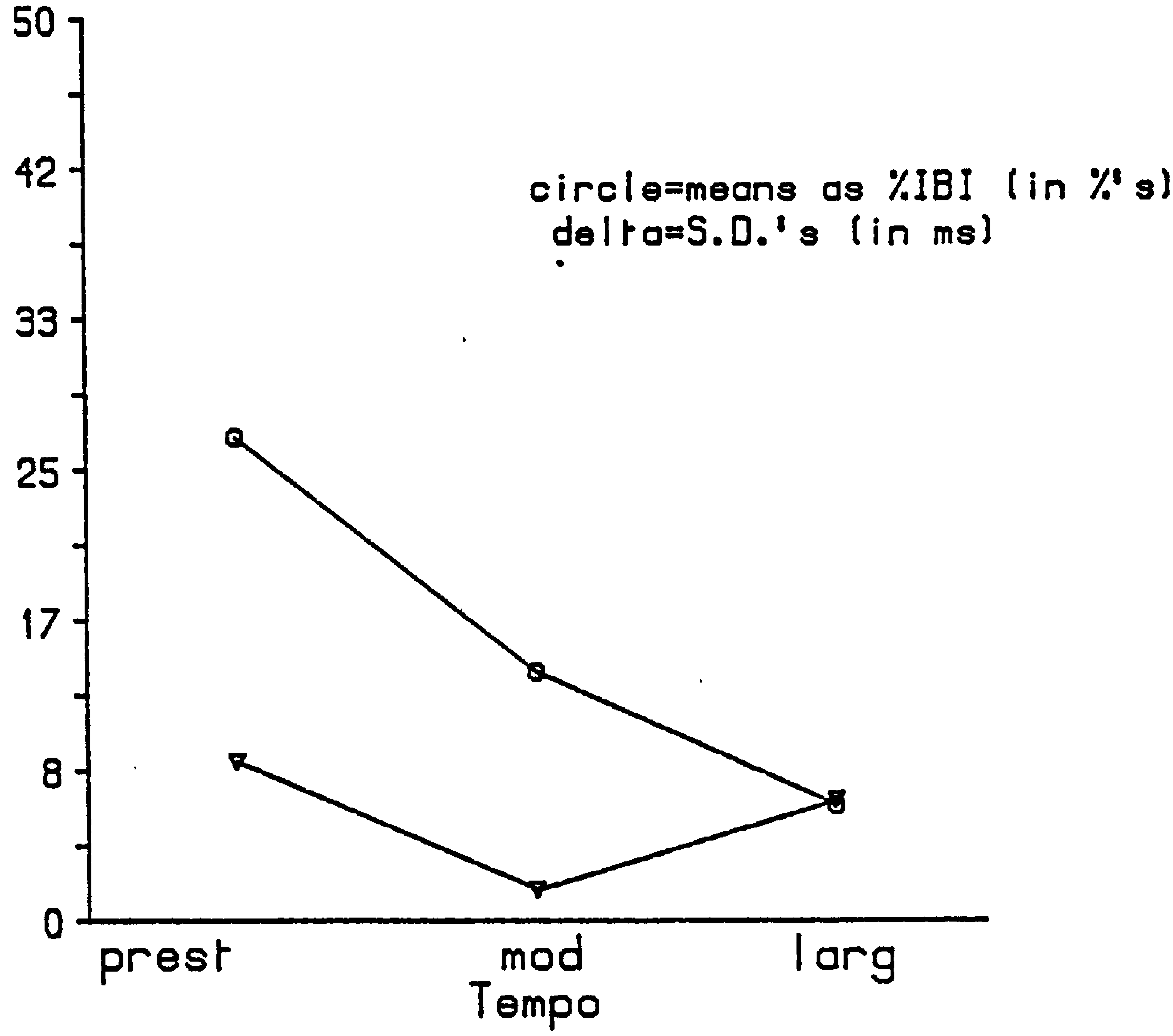
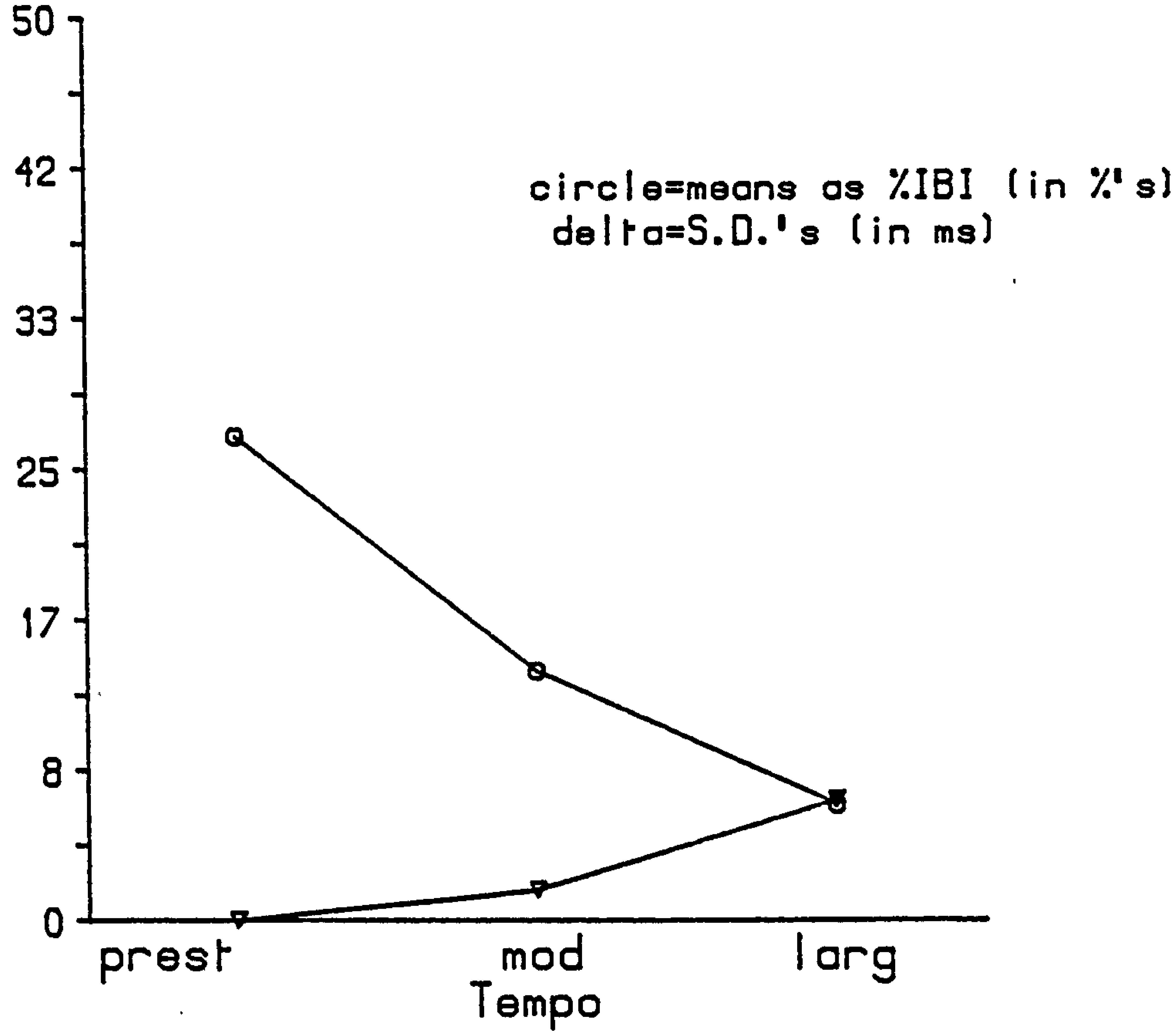


Figure 6.5
Mean offsets as IBI percentages
and S.D.'s, against tempo
Subject T.S.
Block 3 at prestissimo subdivided



details of this test are given in Greene and d'Oliveira (1982). The tables of significance used are those given in Sillito (1947), the only author to give significance levels for N=1 data (where N=sample size), as we have here a ranking of S.D.'s, which of course are derived from N=5 samples, but which are reduced to an N=1 ranking.

Although the absolute size of the difference is small, the test for small samples demands perfect linearity before significance can be granted.

Effect of Tempo: conclusion.

Thus the strongest statement that can be made on the basis of A.M.'s data is that it remains possible that tempo affects both the size of the offset selected (which varies as a percentage of the IBI) and the accuracy with which an offset can be replicated within a block of trials (S.D. of blocks). The effect is not proven here. Note that for the purposes of the above analysis, the block of trials corresponding to the first run at prestissimo was selected. Exactly the same result profile obtains if we use the third run at that tempo, but the data from the second block (where, incidentally, the subject's concentration was subsequently found to have been impaired) weakens the linearity further insofar as it has a larger S.D. than the other replications. The difference is enough to displace its rank from first to second. The percentage rankings, however, remain unaltered.

Of the four rankings for the two subjects, only T.S.'s percentages ranking could be significant. This, however, is only true as long as block 3 at prestissimo is taken as a whole. If we allow the subdivision of block 3, then both T.S.'s rankings achieve perfect linearity. The means as percentages of the IBI's are inversely related to tempo, and the S.D.'s of each block of trials are linearly related to tempo. However, as the sample size here is small (three instead of five), this is not sufficient to compensate for the other non-linearities in A.M.'s data.

Although it is clearly not proven to a precise uncertainty level for both subjects that linearity has obtained, it is also clear, when we take into account the absolute values as well as the rankings, that some measure of effect of tempo can be seen in the data. Part of the explanation may be as follows. The absolute size and direction of the offsets is quite clearly not linearly related to tempo. This is easily demonstrated.

Take A.M.'s results first. The mean offset for larghetto was closest to that of allegretto. With prestissimo, in all three sets of trials, the means were positive, which means the auditory events occurred before the visual. Yet for every other tempo the means were negative. With T.S., the nearest mean offset to that obtained at block 2 at prestissimo was larghetto. The largest offset was obtained at neither extreme, but at moderato. With T.S., every offset was positive.

The offsets, when their absolute size was taken in conjunction with their S.D.'s, and they were compared across trial blocks, were quite clearly from different populations. This was true for both subjects. With A.M., there were seven trial blocks. Each distribution of results within one block could overlap with six others. Thus there are forty-two cross-matches. Half of these are, of course, duplicates, so there are in fact twenty-one possible overlaps. There are only four cases (out of the possible twenty-one) where the distributions of two chosen offsets overlap (taking as the criterion two S.D.'s about each mean). In one of those cases the overlap was marginal, in two cases the overlap totalled 50%, and in one case only (moderato and andante) was one distribution contained entirely within the range of another.

With T.S., there were five trial blocks. Each distribution could overlap with four others, thus there are twenty cross-matches. Subtracting duplicates, there are ten possible overlaps. Out of these ten possibles, there is one very marginal overlap, between larghetto and prestissimo, and just one 100% overlap, where the distributions around prestissimo 3 (all five cases) and prestissimo 1 almost entirely coincide. If prestissimo 3 is subdivided this correspondence weakens, the larger subgroup remaining within range and the smaller becoming distinct.

The overlap of the distributions is shown schematically in tables nine (A.M.'s data) and ten (T.S.'s data).

Table nine

Subject A.M.- Coincidence of distributions

Trial	pres1	pres2	pres3	alleg	moder	andan	largh
pres1	*	-	-	-	-	-	-
pres2	-	*	-	-	-	-	-
pres3	-	-	*	-	-	-	-
alleg	-	-	-	*	-	50	50
moder	-	-	-	-	*	100	-
andan	-	-	-	50	50	*	J
largh	-	-	-	50	-	J	*

Table ten

Subject T.S.- Coincidence of Distributions

Trial	pres1	pres2	pres3	-	moder	-	largh
pres1	*	-	100		-		J
pres2	-	*	-		-		-
pres3	100	-	*		-		-
-							
moder	-	-	-		*		-
-							
largh	J	-	-		-		*

Comments on Tables nine and ten: These tables are schematic. Figures given are guidelines only. Thus:

100 = One distribution contained almost exactly within another.

50 = Distributions overlap to about half their extent.

J = Distributions just coincide at two S.D.'s each way.

Note that in table nine the two sides of the matrix are not equivalent. This is because the distribution at moderato occupies only half the range of the distribution at andante. Thus all of the moderato range is contained within the andante range, while only half the andante range coincides with moderato scores.

So we see that for both subjects, offset sets are clearly distinguishable. Absolute offset size therefore varies between sets. In addition, absolute offset size is also clearly independent of tempo.

However, in relation to the large differences in the gradations in tempi (IBI's from 340ms to 1200ms) the absolute size of the offsets remains relatively constant- that is, offset size varies over a much smaller range- which is of course why there was an apparent covariance between tempo and offset size expressed as a percentage of the IBI.

This does not of course explain why the variability with which the subject selected an offset should also to some extent covary with tempo. Here, as mentioned, the relationship between the two was actually stronger. With A.M., the smallest S.D. (0.8ms) was obtained with the largest actual discrepancy (126.6ms) so although there was a large visual-auditory difference, the subject was selecting this offset very consistently. The relationship between size of offset and S.D. is not however linear, the largest S.D.(11.5ms) was obtained in conjunction with the second largest offset (-59.2ms).

With T.S., the largest offset (106.4ms) obtains with the smallest S.D. (1.7ms) again, but at moderato this time. If, however, we split the third block at prestissimo, the smallest S.D. now becomes 0.0ms but obtains with an offset only slightly smaller (101.7ms).

So again we see a large visual-auditory asynchrony being very precisely selected and re-selected. However, the S.D.-offset size relationship is essentially as erratic with T.S. as it is with A.M., the largest S.D. (8.8ms) obtaining with the next largest offset: 91.1ms at prestissimo 1. Then an S.D. which is only slightly smaller (8.4ms) obtains with the smallest offset T.S. achieved, 54.9ms at prestissimo 2.

Thus tempo is in fact the sole candidate for a covariance with S.D. size. Figures 6.6 (A.M. data) and 6.7 (T.S. data) show the S.D.'s plotted against IBI, and figures 6.8 (A.M. data) and 6.9 (T.S. data) show S.D.-IBI plotted against IBI, i.e., as a function of the IBI. Note especially that if the extreme and midrange conditions only were used (prestissimo, larghetto, and moderato) the S.D.-IBI function would be perfectly linear.

The relationship between accuracy (as measured by variance of responses) and tempo is discussed further in chapter eight.

Part two: Strategy- a higher level invariant.

Now consider questions one and two of the introduction in conjunction, in relation to the question of strategy. What follows is a list of all the possible results that could have emerged from this investigation, along with the model that would have been supported in each case.

(a) If the asynchronies selected varied randomly, irrespective of condition, then all that could be ascertained are the limen of discriminability.

Figure 6.6
S.D.'s against IBI
Subject A.M.

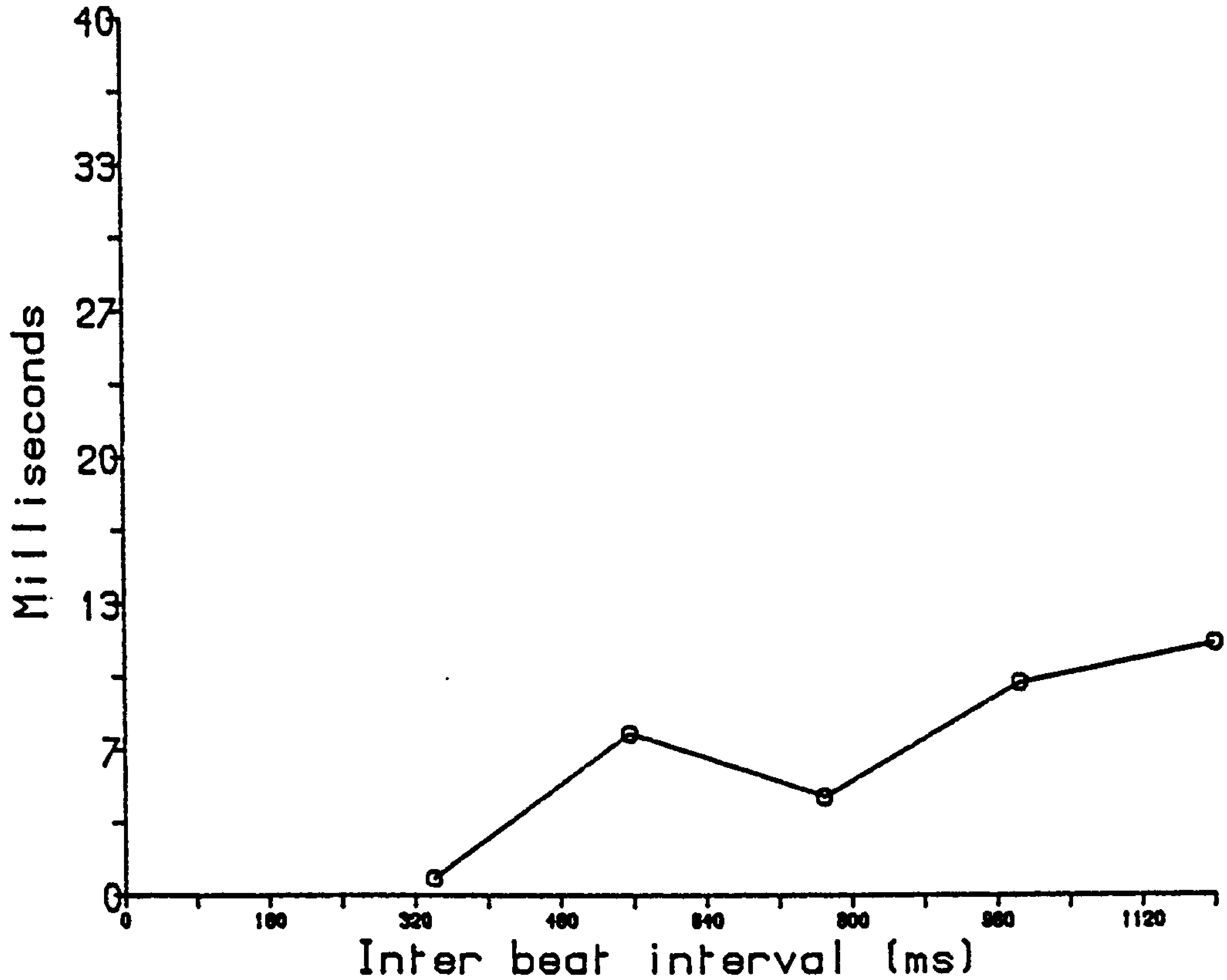


Figure 6.7
S.D.'s against IBI
Subject T.S.

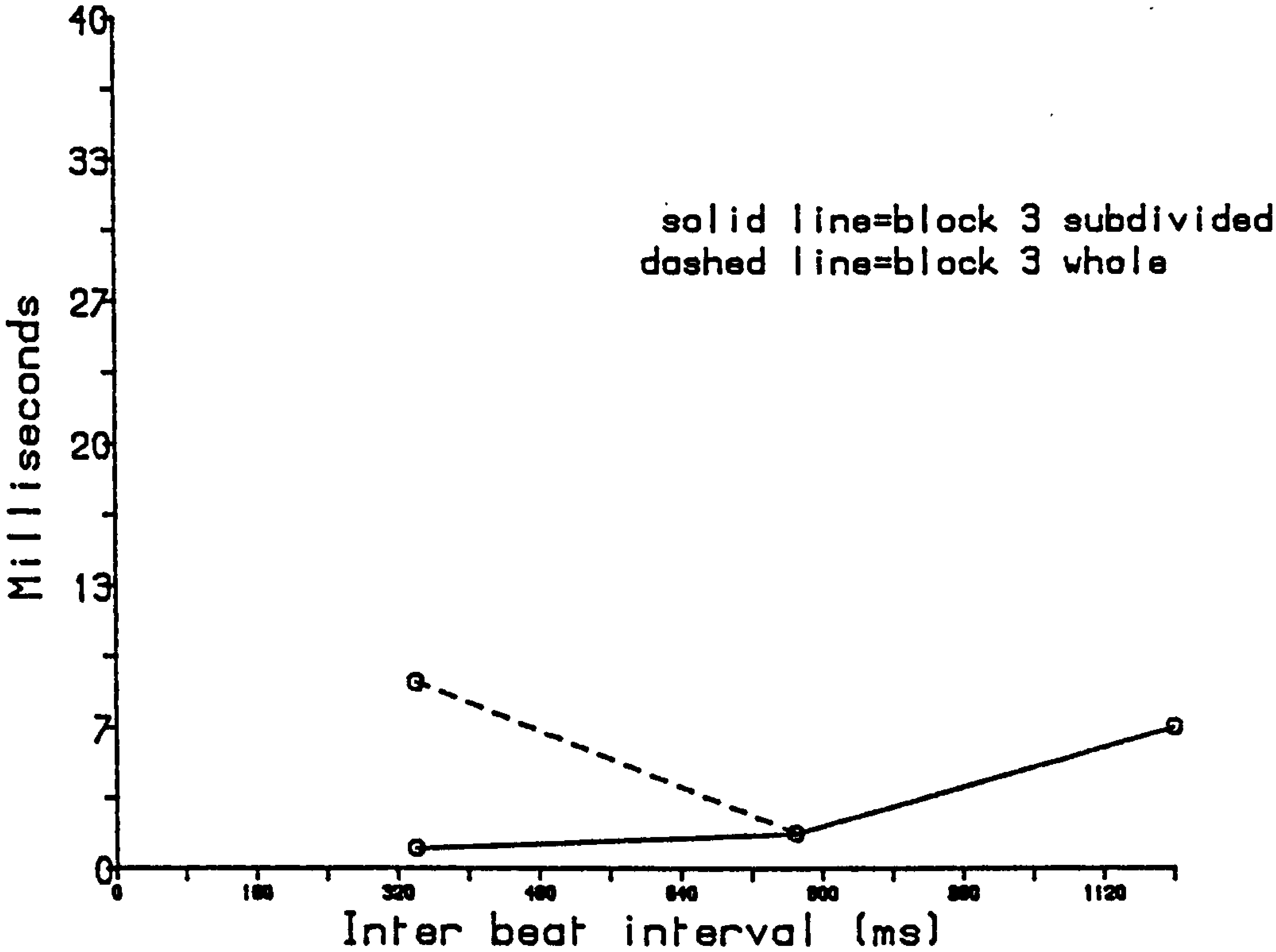


Figure 6.8
Mean offsets as IBI percentages against IBI
Subject A.M.

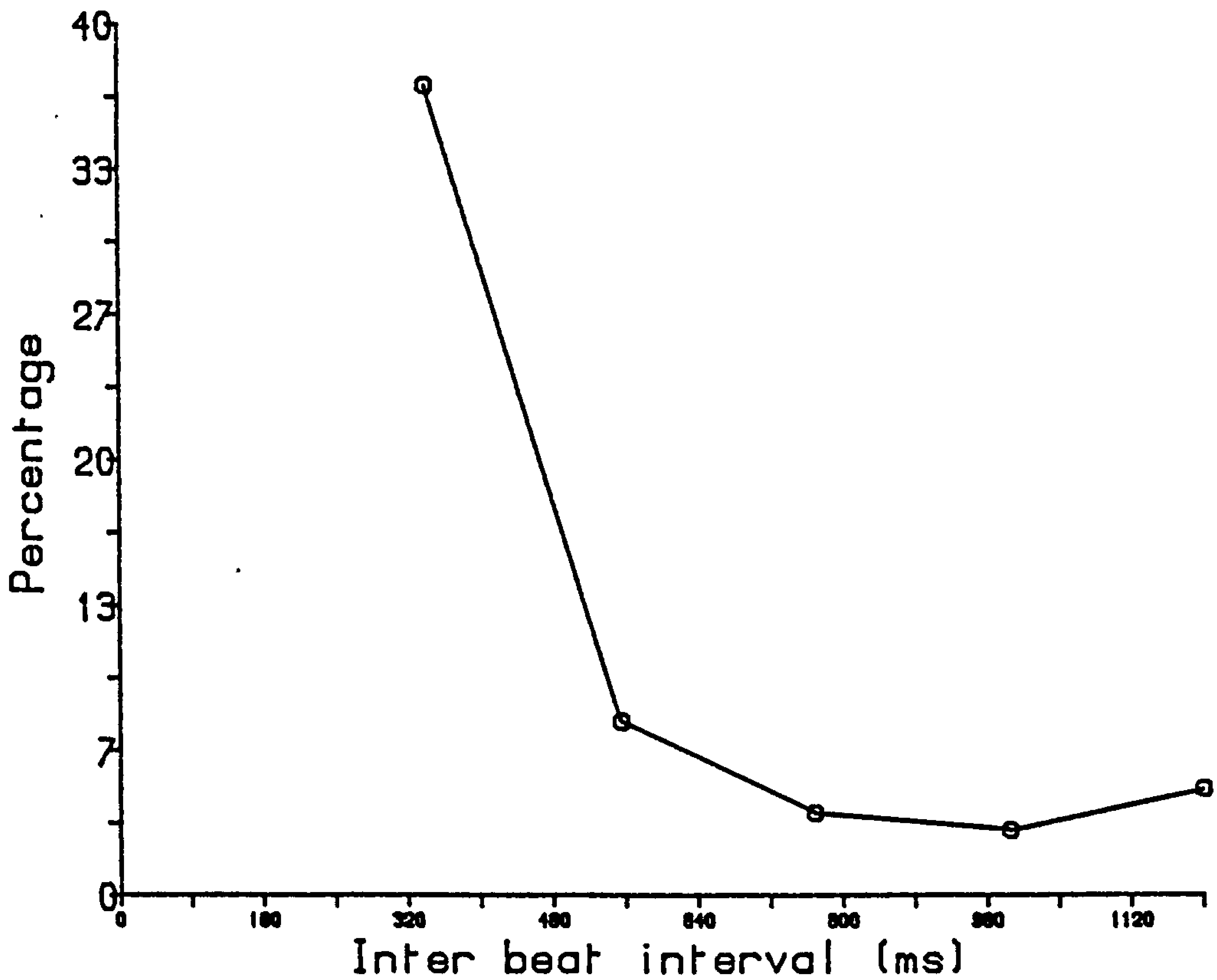
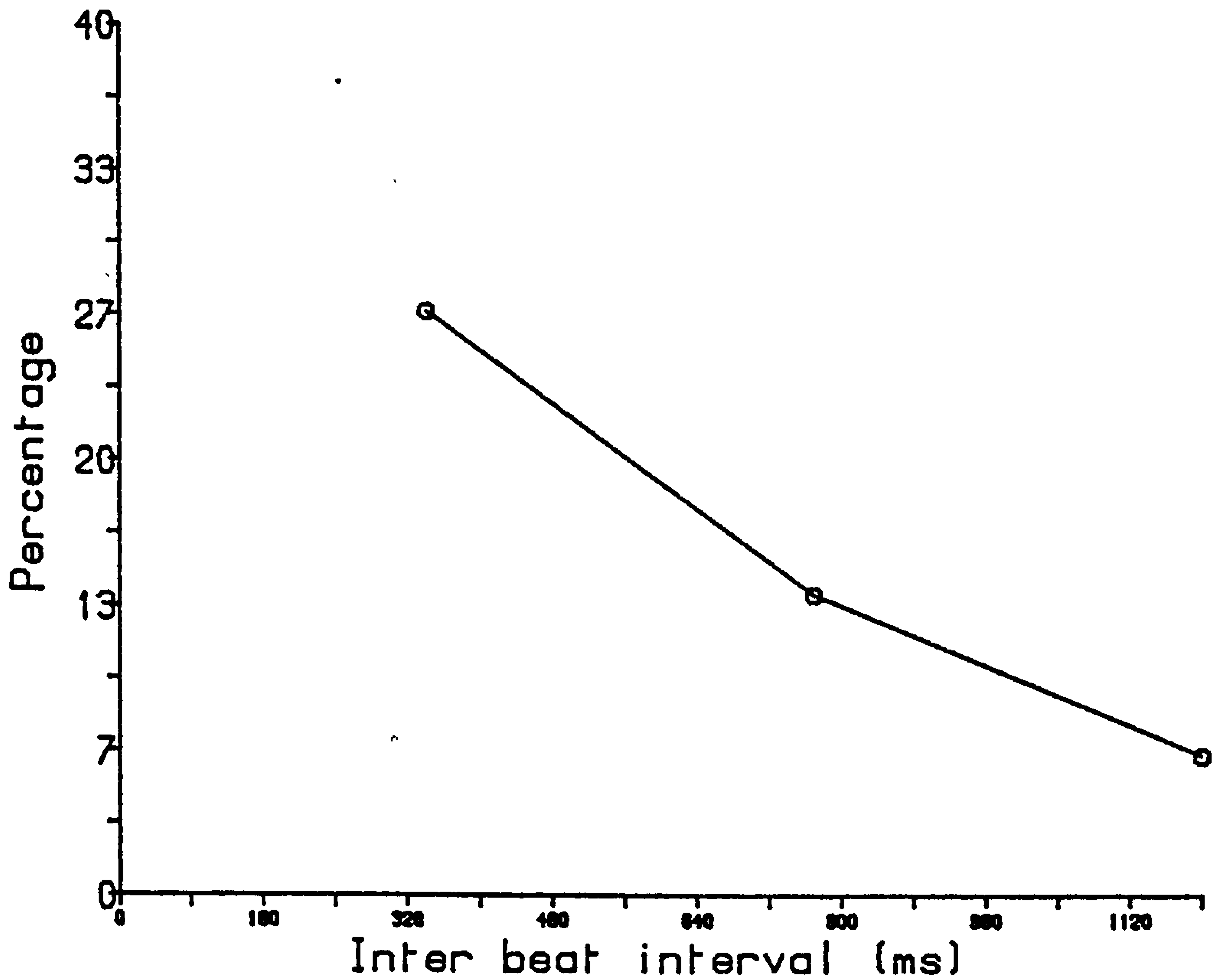


Figure 6.9
Mean offsets as IBI percentages
against IBI
Subject T.S.



(b) If the degree of asynchrony remains invariant within blocks of trials, between replications of trials, and over different tempi in absolute terms, then this must be explained in terms of an absolute limen of discriminability.

(c) If the degree of asynchrony remains invariant in relative terms- as a fraction of the IBI, i.e. as a temporal function, and the same degree of asynchrony occurred in replications at the same tempo- then the conclusion would still be that a limen existed: but with the addition that it manifested as a function of the time interval. This would require that results varied systematically by tempo.

(d) If the asynchrony is not invariant, either in absolute or percentage terms, but the subject can reproduce a given degree of asynchrony within a block of trials at a given tempo, then the conclusion would be that a stable strategy had been adopted, and the invariance resulted from this level. This would mean that an explanation in purely psychophysical terms would not be sufficient.

(e) If the result profile in (d) is obtained within any given block of trials, but varied across bands of tempi in a systematic manner, then the conclusion would be that the adoption of a particular strategy is influenced or determined by an overall temporal parameter or limiting factor.

(f) If if the result profile in (d) is obtained within any given block of trials but varied over different replications at one tempo then the conclusion would be that the strategy itself was not absolute and that a superordinate principle of strategy gave rise to the observed consistencies. This last distinction will become clearer as we examine the results.

Now consider what actually emerged. In Tables three and five it can be seen that the subjects achieve the same degree of offset within each block of trials, with the occasional rare exception. Examination of the S.D.'s confirms the tightness of the grouping. For A.M., S.D.'s for five trials ranged from 11.5ms in the worst case (larghetto) to 0.8ms in the best (prestissimo). This is after the removal of one anomalous trial in prestissimo (2) and one in the andante block. For T.S., the largest S.D. is 8.8ms, the smallest is 0.0ms if we allow the subdivision of the third block at prestissimo, or 1.7 at moderato if we do not. Responses are therefore clearly not random. This disposes of option (a).

It is equally clear that the absolute degree of asynchrony, while tending to remain constant and tightly clustered within any given block of trials, does not remain invariant across blocks of trials. This is true for both subjects. This disposes of option (b).

If we now examine A.M.'s three replications at one tempo (prestissimo), taken over different days with a masking of intervening trials at other tempi, we see that the subject chose entirely different offsets on each day (of 126.6, 32.5, 48.2ms). Within each block of trials, however, the offsets were tightly clustered- achieving, in one case, a S.D. of 0.8ms. The degree of asynchrony was not replicated within successive trials at one tempo even though the selection of offset was stable within each block of trials. That is, once the subject has selected an offset, he can repeatedly re-adjust the delay between the series and arrive at the same offset time after time. This initial selection is clearly not determined by psychophysical parameters, as it is not invariant in absolute temporal or spatial terms, even though the accuracy with which the subject can return to the same offset might well be.

T.S.'s data fits this pattern exactly. With the replication blocks at prestissimo we again observe the selection of different offsets between blocks of trials. In the first run, T.S. set the events 91.1ms apart. In the second run, the offset selected was 54.9ms. In the third run, the offset was of the same order as in the first run, 92.9ms. These blocks were recorded in that order, with one week intervening between the recording of blocks 1 and 2, and one hour between blocks 2 and 3. The difference between the largest and smallest offset is equal to 4.7 standard deviations, and therefore quite clear.

If we examine the third run at prestissimo more closely, we see something even more interesting. T.S., in the first two trials, set the offset to exactly the same value, 101.7ms. On the third trial, she reset the offset to around 87.0ms and selected that offset for the remaining trials, with an S.D. for the last three trials of only 1.0ms. Thus we have, within one block of trials, a clear selection of two different offsets, each offset successfully targetted, with the switch between the two halfway through the block.

The very small size of the S.D.'s indicates that it might actually be misleading to average the two selections together within the third block and take the overall S.D. to reflect the accuracy with which the subject made her selections.

This is the only time a switch within a block of trials was observed. It is not known what caused the subject to change her mind as to what constituted acceptable synchrony within a block.

These results from both subjects clearly dispose of option (c) and mean, in effect, that we must now consider questions of strategy.

As regards option (e): the selection of offset size, as we have seen, does not covary with tempo and thus can be deemed independent. The accuracy with which subjects can return to the same offset (the S.D.'s within blocks) does give some indication of varying by tempo. This further supports the distinction made in the last paragraph between (1) the offset selection, which is apparently an independent choice, and (2) the accuracy with which the subject can replicate within a given set of trials.

As the degree of offset can vary across blocks of trials at the same tempo, we cannot conclude that the choice of strategy is itself determined by situational parameters (which means that the "basic" option (d) cannot hold). Thus we are left with option (f)- that the player applies a strategic principle to the task. A point of acceptable asynchrony must be selected, but there is clearly little constraint in the choice (even to the extent of choosing an offset equal to approximately one-third [A.M.] or one-seventh [T.S.] of the

IBI). The directionality of the offset is also apparently a matter for choice: although A.M.'s general preference was for the visual event to antecede the auditory, in one condition he consistently reversed the preferred direction.

It is from this level therefore that invariance must ensue- having made the choice, the subject can obviously find the point again, although the accuracy with which he can do so may be parameterised by psychophysical limitations.

Discussion

This is clearly a two-stage process. The first stage is the selection of the offset between the visual and auditory events. This degree of asynchrony has been observed to be as small as 3.0% [A.M.] or 6.5% [T.S.] of the IBI, and as large as 37.2% [A.M.] or 29.9% [T.S.] of the IBI. The selection appears to be independent of tempo. The same selection will not necessarily be made in otherwise identical conditions at different times. In conclusion, the selection appears to be arbitrary. In making this selection, the subject is, then, applying the principle of a strategy. This principle could be translated roughly as "pick a spot- and then stick to it". At this point, an item of anecdotal evidence might help. The subject A.M. told me, when I asked him to describe to me how he thought he solved the task, that he took

> "A kind of photo of the disk with the position of the markers in my mind- and then I try to match up the position of the disk (in later trials) with the photo."

All indications included, there is a strong suggestion that the subject forms a very clear schematic representation of the orientation or position of the markers. This image is then used as a comparator or template against which the observation of the current visual information is assessed. This process appears to be semi-independent of the actual orientation of the disk, as the subject did not always obey the instruction to synchronise the auditory event with a visual event that was referenced by a fixed marker exactly in front of the subject (at the 180 degree position on the disk). In spite of this, the process clearly could allow great accuracy in replicating a given orientation, once selected.

The second stage in this model is a process which can be described in psychophysical terms: the ability of the subject to correctly replicate performance (or match up the "photo" and the markers) either "passively" (judgement of asynchrony) or "actively" (producing taps to coincide with a temporal target).

Note the key point that it is necessary first to define the subject's target or goal before any attempt can be made to measure the accuracy with which the subject can replicate performance. We must know what the subject is aiming at before we can assess competence.

An analogy may be drawn between the necessity to structure the analysis in this fashion and the necessity to distinguish between interpretation and skilled performance described by Michon (1967) in the following words.

> "We might, for instance, study the performance of a pianist playing a Beethoven sonata and measure to what extent his performance would be in agreement with the specified duration of each note in the score. Melody and intensity would enter the picture only insofar as they would affect the precision of the temporal relations. A pianist will be called a 'skilled performer' even by his least benevolent critic, so long as his timing is impeccable, although his 'interpretation' may be way below an acceptable minimum."

Michon then goes on to point out that there is in fact evidence that interpretation is accomplished at least as often by introducing well balanced variations in the timing of notes as by varying their loudness. (Henderson (1936), Stetson and Tuthill (1923))

That is, we cannot assess deviations from the strict relative timing specified by a score as simply errors without some consideration of the possibility that the self-set temporal goal of the performer deviated from the specified temporal goal and was possibly achieved correctly. Consider this two stage process in the context of the achieving of ensemble between conductors and musicians. Remember the conclusions of chapters two and three. The achieving of ensemble may in fact be the arrival in rehearsal of a consensus as to what constitutes the temporal goal, and what parameterises the system for communications on these goals. The conductor moves the baton in a continuous trajectory, defined in the three positional dimensions and in terms of velocity and acceleration. There are different phases of this trajectory which can be used to unfold a coherent temporal structure, but there appears to be no absolute law that one phase should be selected always in preference to another, although there are certain conventions there are few or no laws (even that a beat should occur near the top or bottom of a baton arc) that are immutable.

However, the conductor and players can and do agree on which phases are to be used. This first stage having been achieved, we then move onto the second stage where the players must continuously achieve a correct structure in their playing- which involves the ability to make correct judgements and also the ability to actualise correctly the required movement structure within the defined temporal period.

Chapter Seven

Grouping

Abstract

The problem of timing of interresponse intervals is discussed. It is noted that previous work in the field of targetted tapping has tended to use relatively short sequences, typically twenty taps. It is suggested that this is too short to permit the observation of spontaneous grouping of responses. An experiment was done to discover whether, given a sufficiently long recording period, higher order grouping would invariably emerge, even with an isochronic target series. A series of recordings was made, at one tempo only (moderato). In the majority of trials, a grouping base could be identified. There was an overall preference for four as a base.

Introduction

Vorberg and Hambuch (1978) divide the problem of timing of interresponse intervals into two parts. The first problem is that of the serial ordering of behaviour, as described by Lashley (1951). The second is that of the timing of segments in the behavior flow.

Noteboom (1974) demonstrated that utterances which were well formed with regard to serial order could still not be understood without additional constraints on the durations of individual phonemes. The problem of making music can certainly be conceptually subdivided in a parallel fashion. There is serial ordering of pitch, volume and phrasing, which forms the melody, and the timing of individual segments, which forms the rhythm.

A number of authors, including Estes (1972), Martin (1972), Jones (1974, 1976a, b, 1981), and Shaffer (1976, 1980), generally concur with Lashley in postulating hierarchic representations that control serially ordered behaviour. Lashley clearly demonstrated the theoretical inadaquacy of sequential organisational structure.

Less is known about the hypothesized timing mechanisms, assuming for the moment that the conceptual distinction between serial ordering and segment timing is correct. This second problem is the one addressed by Wing and Kristofferson (1973(a) and (b)). Following a suggestion of Voillaume (1971) and Fraisse and Voillaume (1971) they have developed a two-stage model of temporal responding. Firstly, a central timer emits a train of pulses. The intervals generated are assumed to be independently and identically distributed. Secondly, on being triggered by a timekeeper pulse, a response generating mechanism actualizes a response after a variable period of delay. These delays are also assumed to be independently and identically distributed. The first version of this model postulated a deterministic central timer and a fallible response generator. A later version of this model allowed both stages to contribute to the variance of the interresponse intervals while remaining absolutely independent. This postulated independence is supported by the following observation: with longer intervals to reproduce, the variation in the timer output increases, while the motor delay characteristics are unaffected. This would certainly be one way of accounting for the observed relationship between tempo and accuracy reported in chapter two, and discussed in chapter eight. With motor responses, on the other hand, Wing (1977) found that the more gross the movement, the less variable. Finger tap responses varied more than rotations around the elbow. Wing suggested here that the finer the control associated with a limb, the more complex the programming required.

This two-stage model is then used to explain observed negative covariation between adjacent response intervals (lag-one autocovariance) when subjects make repetitive responses. The assumption that the timekeeper delays and the motor delays are sequences of independent random variables implies that the covariance between any two successive inter-response intervals (IRI's) will be negative, while nonadjacent IRI's will not covary.

In other words, long IRI's will tend to be followed by short IRI's, and vice-versa. This is not due to any error-correcting mechanism built into the model, nor is it really grouping as such, as the timekeeper and motor delay intervals are assumed to be mutually independent. By an analysis of the precise nature of the inter-tap-interval autocovariance function, Wing then attempted to define the nature of the dependencies on either the level of the timekeeper or the response generator. The conclusion was that the observations could be accounted for by the assumption either of a first-order dependency or of a first-order moving average process amongst adjacent response delays, with independent timekeeper intervals in both cases. This two-stage model is quite closely related to that proposed by Kozhevnikov and Chistovich (1965) for speech timing. Wing, in a paper delivered in 1981 at Edinburgh University, also suggested that coordination of bimanual actions was achieved before the timing process, and that the process of timing was an essentially low-level operation on pre-prepared information.

We have now, therefore, a three-stage process. Stage one is the level at which serial ordering and possibly also coordination of actions is achieved, stage two supplies the timing but is itself subdivided into two stages, (a) the timekeeper and, (b) the response generator.

Vorberg and Hambuch found Wing's model cannot be generalized to explain rhythmic tasks which have a target series more complex than isochronicity. Vorberg and Hambuch's subjects were "induced" (see below) to group responses in a tapping task, with a grouping base of one, two, three or four, at two different tempi. The results with a base of one (effectively ungrouped) support the Wing model, but with grouping bases greater than one they found significant positive dependencies between IRI's. The positive peaks in the serial covariance functions occurred at lags identical to the grouping base.

When Vorberg and Hambuch looked at the means of the different IRI's within groups, they found "slight but significant" differences in some (but not all) conditions. The pattern of results was "highly idiosyncratic". Povel (1977) obtained a similar finding with the structure of recorded music.

Thus Vorberg and Hambuch found real evidence for higher level unit organization, which they suggested must be achieved by another group of timekeepers, one for each of the grouping bases. They do not specify what must happen with grouping bases greater than four. Either a timekeeper must exist for every possible grouping base, which would surely be rather unwieldy, or else larger grouping bases are made up of complexes of smaller ones. For example, a grouping in sevens could be made up by two groupings, one of four and one of three, running in sequence. In this case it would be necessary to add yet another tier of organization to explain the coordination and assembly of the component timekeepers.

Vorberg and Hambuch tried to ascertain exactly how the timekeepers were organized into groups. They compared a sequential chaining model, where it was presumed that each timekeeper triggered the next after a delay, with a second model, a single hierarchy with one timekeeper controlling the group duration and other timekeepers controlling responses within the group, and finally a third, a fully hierarchic model with timekeeper one controlling the onset of the group, timekeeper three halving the group, and timekeepers two and four subdividing each half-group.

The results were inconclusive at their slow tempo (IRI= 500ms= 120 beats per minute= allegro) but at their fast tempo (IRI= 300ms= 200 beats per minute= prestissimo) the sequential model appeared to be supported by the response variance-covariance structure analysis. That is, they found no difference in the sum of the variances of N successive IRI's when taken across group boundaries, as opposed to within (N represents the grouping base). This sequential model thus supported by both the Wing and Vorberg & Hambuch analyses is similar to the "comb" or pre-planning model for speech timing proposed by Kozhevnikov and Chistovich (1965).

Thus Vorberg and Hambuch concluded that there was a basic inconsistency in their results, between the finding of real evidence for grouping on the one hand and the failure to find clear IRI differences and a supra-sequential organizational structure on the other. This led them to the conclusion that two levels of organisation existed. These were, as previously stated, serial ordering and segment timing. Their first result, then, demonstrated the functioning of the serial ordering level, their other findings the segment timing level. This interpretation is consistent with that of Martin (1972) and Michon (1974).

There are a number of additional problems with the Wing and Vorberg and Hambuch model. Firstly, Vorberg and Hambuch do not attempt to tackle the problem of unequal as well as equal subdivisions of the grouped interval, although they suggest that their model could in theory be extended to cover that eventuality.

Secondly, neither Wing nor Vorberg and Hambuch make any allowance for feedback. Feedback could have two roles. It could be used to monitor and correct perceived error by adjusting subsequent response intervals. It could also be used in anticipating and accomodating to known differences in motoric response characteristics when the response may be made with different types of movement.

Thirdly, the basic Wing model, as Vorberg and Hambuch rightly point out, is concerned exclusively with a level of organisation which cannot explain the grouping of responses. The reported results did not always match the expected profile. This may be because the authors were attempting to account for them in terms of an "adjacent intervals" analysis.

Fourthly, Vorberg and Hambuch did not consider the possibility of a predictive rather than a reactive mode of response to a timekeeper-set series. They assumed the "clock" would control the onset of an interval, whereas, as Shaffer (1982) points out, a clock may equally well set a target time point. This is an interpretation which accords much more realistically with the problem faced by a musician who must anticipate a conductor's beat. Thus Vorberg and Hambuch expressed surprise when they found that the first IRI in a group tended to be the most variable. They assumed that the last IRI in a group should be most variable because they were thinking in terms of a reactive triggering model. If a timekeeper alters the degrees of freedom of a group of responses by controlling the onset and overall duration of the group, then the last interval in the group will be the most variable, on average, as the accumulated error would then have to be absorbed. However, if a timekeeper controls duration and terminus of a group of responses, then the responses would become progressively constrained, with the proportionately greater number of degrees of freedom being expended near the onset. Thus this finding actually supports Shaffer's predictive model.

Fifthly, the finding by Vorberg and Hambuch that they obtained apparently purely sequential organization in one condition only (at an IRI of 300ms) may have an alternative interpretation. This is that at an IRI of approximately 300ms organization is rendered impossible at the superordinate level at which grouping is effected. The conductor G.T. who participated in some of the experiments reported (in chapters two, three, and four) considered that there was a critical frequency above which he would only conduct multiples (every second or third) rather than every individual beat. This frequency he estimated to be an inter- beat- interval (IBI) of 340ms

(176 beats per minute, which is a presto). The range of tempi which was evolved in consultation with the musicians who participated in these studies lay between a larghetto with an IBI of 1200ms (which is 50 beats per minute) to a prestissimo with an IBI= 340ms. This may approximate to what Kelso et al (1981) termed a range parameterised by non-linearities. Analogously, the horse's walk, trot, and gallop are not linearly related in the way that, for example, a slow and fast gallop are. There are qualitative differences in the functional organisation of the coordination of the limbs. Vorberg and Hambuch may have been asking their subjects to transgress a non-linearity by asking them to group their responses at that fast a tempo. That interpretation is supported by the qualitative differences in their findings at the 300ms and the 500ms rates.

Sixthly, and finally, the Wing and Vorberg and Hambuch models necessarily becomes rather complicated. First, the problem of timing of interresponse intervals must be divided into two parts, serial ordering and then segment timing. There is general agreement in the literature on this point. They then further divide the segment timing section into two domains, a timekeeper and a response actualiser. This alone cannot account for all results, such as the grouping phenomenon, so additional timekeepers must be added to organize the timekeepers and assemble them in different combinations. At this supra-timekeeper level we may have to postulate that there are further clocks that must be engaged at the level of immediate response to serial ordering, and that these clocks deploy, assemble and time the running of component blocks of clocks, each of them with dependent clocks.

Thus the initial assumption that the segment timing level consists of two stages, which vary independently, leads inevitably to a plethora of clocks.

There is an alternative approach which focusses on "process rather than product", described by Kelso et al (1980,1981), Turvey (1980), Kugler et al (1980,1982), and Fowler (1979).

Kelso et al (1981), analysed Bernstein's (1967) problem of the regulation of the degrees of freedom of the motor system. They base their approach on an intrinsically rhythmic or cyclic model of interlimb coordination. They state that the functional muscle system can be best described as having all the characteristics of a limit cycle oscillator. The limit cycle oscillator model was originally proposed by Von Holst (1937). Thus there is an inherent tendency to maintain frequency (which would subsume part of the role of the timekeepers) and amplitude (which Wing would allocate to the domain of the motoric response generating system).

In a system with multiple limit cycle oscillators there should be an inherent tendency towards mutual entrainment. Kelso obtained this result in a bimanual task study. He also suggested that Shaffer's (1980) work with pianists revealed essentially the same basic principle of superimposition for combining the outputs of coupled oscillators. A further extension of this concept could explain how it is possible to entrain an oscillation cycle with an external frequency, as when we fall into step with a marching band or tap our feet to a beat.

The first critical conclusion is that these characteristics are system-emergent properties. This, if true, could greatly reduce the number of clocks we must otherwise postulate. As timing function is now seen as a system-emergent property, this is an alternative to the "clock plus reaction computational method" in a way analogous to that in which the tau strategy described by Lee et al (1983) is an alternative to the "distance plus speed computational method".

The second crucial point is that this system of limit cycle oscillators could be driven at different frequencies. An adjustment to an organizational parameter of the functional or synergistic muscle grouping could determine the nature of the oscillatory system frequencies (the temporal subdivisions) while the system as a whole is driven at an independently determined frequency. Thus there is a certain parallel with the Wing and Vorberg and Hambuch models. The key difference is that we do not need to postulate a deterministic timekeeper, or program, or system of timekeepers, set in an autocratic relationship to motor actualizers. The Kelso model assumes a heterarchical relationship between the frequency selector and the synergistic system properties, with different modes of interaction. Thus frequency, or amplitude, and component frequencies could be modulated by adjusting respectively the frequency selector or the synergy.

Another possibility which might explain the grouping phenomenon (the appearance of component frequencies) is that the "central generator" (to use Fel'dman's (1980) term), or the frequency selector, or driver, could be characterised as having an analogue output (in contrast to the "digital" clocks) which could be linearly adjusted to run the system at different frequencies with non-linearities demarcating different sections of the range. The analogue output of the driver could be a complex of frequencies which could in effect be "factorised" or "Fourier transformed" to give the component periodicities.

This then would be an alternative to adjusting the synergistic combination of the muscle systems. The two strategies need not even be mutually exclusive. It is even possible that the non-linearities observed by Kelso in fact reflect the operational ranges of the muscle synergy rather than of the central driver and are thus more properly described as system-emergent properties.

This could explain why the conductor G.T., who participated in the experiments reported in chapters two, three, and four of this thesis could not conduct faster than an IBI of 375ms without conducting multiples, nor slower than an IBI of 1200ms without subdividing.

Consider the analogy of gait again. Each of the phases of one step-cycle: the push off, leg raise, swing through, and place, could be considered as forming the component periodicities. Suppose we are running at a constant speed, then have to accelerate. An increase in the driving frequency could affect all component phases of the action to approximately the same extent, as might happen for a relatively slight increase in speed. Alternatively, a differential increase in a component driving frequency or a reorganisation of the synergistic system might be required for a change in gait. One characteristic of limit cycle oscillators is the means whereby they compensate for dissipative losses, often by employing an escapement to inject energy into the system. In the case of running, an increased force applied in the push off from the ground will increase the length of time the runner remains in the air and hence the amount of foreward ground gained. This would thus necessitate a reorganisation of the contributing frequencies of the other phases of the stepcycle, while maintaining the overall stability and cyclicity of the operational mode.

Grouping as a system property

If rhythmicity is an inherent feature of a muscle synergy organised for production of repeated responses, then grouping, which is a second order of rhythmic organisation, could equally be considered to be an inherent feature of the dynamic heterarchical interrelationship between the frequency driver and the muscle synergy.

If it is true that grouping should be properly considered as inherent in the dynamics of the system, then a further limitation of the Wing-Vorberg and Hambuch approach becomes apparent. This is their failure to consider that a subject's ability to follow an isochronic target series might reflect a special case- the deployment of a grouping base of one, rather than exemplifying the operation of the basic mechanism for the control of the response interval.

To restate the underlying key assumption in general terms, Wing and Vorberg and Hambuch have assumed that the simplest mode of operation which they could define conceptually, and operate as a laboratory task reflected the basic operating mode of the system. This assumption is, of course, common to a considerable opus of work in psychophysics. The immediate corollary to that assumption is the idea that apparently more complex modes of responding must be composed of groups of operations, all on the basic level, which of course necessitates the supposition of various levels of coordination and assembly of basic-level operations.

If the "psychophysical" approach suffers from a misplaced atomism, the main alternative seems to be the "systemic" or "direct" approach represented at the level of organisation of responses by theoreticians such as Kelso, Turvey, and Fitch; by the traditional Gestalt approach to the explanation of perceptual grouping; and in the broader context of the organisation of perception and action by Gibson (1966) and Lee et al (1983).

If response grouping is systemic, then we would predict that it should emerge spontaneously, just as visual gestalten. There is a practical problem here, which is the need to distinguish between lag-one grouping, which is nominally quasi-isochronic, on the one hand, and grouping to bases of greater than lag-one on the other.

The purposes of the experiment

A feature of both Wing and Vorberg and Hambuch studies were the relatively short experimental recording periods employed (usually twenty tap intervals). Given an isochronic target series it is certainly possible for a subject to maintain a lag-one grouping, at least for that length of time. The question then becomes: given an isochronic target series, but a considerably longer period of recording, (a) would higher order groupings then become apparent? and (b) what would these be?

The answer to (b) can only be probabilistic. Grouping to base one is certainly possible, as a lawful subset of an inherent prediliction to group to a base self-selected or imposed, but in Western music it is not common. This is circumstantial evidence that grouping to the base one should be considered as a special and relatively rare instance, rather than the basic mechanism. It does not follow from a consideration of grouping as a systemic phenomenon that all grouping bases are equally easy or likely to be adopted, given a free choice. The reason for this may also be implicit in Kelso's hypothesis of a range of options bordered by non-linearities. That is, there may be grouping bases which may be more parsimoniously or less energetically achieved by redeploying at the level of the synergy, rather than by attempting to drive the existing synergy at an uncomfortable level. As a simple analogy, think of having to maintain a given walking speed at one's natural pace, as compared with having to take artificially short and rapid steps.

The preferred grouping base will probably be influenced by the subject's formal training and practice. As, therefore, most music of our culture is in simple rhythms, such as 2:4, 3:4, 4:4, and 5:4, it is most likely that the base selected will be of this type.

The answer to (a), therefore, cannot be determined precisely. Given an isochronic target series it may be extremely likely that the subject would deploy higher order groupings; but the choice of grouping base might be influenced by factors both within and without the laboratory. The latter refers to the prior experience of the musician. The former is best illustrated by example. Vorberg and Hambuch had their subjects tap as evenly as possible at prescribed rates, but at the same time "induced" them to group their responses by twos, threes, or fours by presenting only every second, third, or fourth tone during the synchronisation phase of a trial. This dimension was explored in the experiment reported here. As this experiment was also concerned with the effect of information modality on the grouping process, it was necessary to find an equivalent method for inducing grouping that could be presented visually. This was done by varying the number of markers on the disk, from three to five, while keeping the IBI constant throughout. The question was, would it be possible to suggest a grouping base via the number of markers on the disk? Given a particular number of markers, would the equivalent grouping base always be adopted? Alternatively, would an idiosyncratic preference dominate, regardless of any "suggestions"?

Control for number of markers

There were other reasons to experimentally vary the number of markers on the disk. One of them was an experimental investigation which is discussed in chapter eight. The other was a control for a methodological problem. It became apparent that minute mechanical imperfections in the apparatus had created an artificial grouping based on one disk revolution. The recordings in the experiments reported in the other chapters were done with four markers on the disk. Four were used for simplicity and convenience. The motor could not drive the disk fast enough for one marker to suffice at the prestissimo speed, and four marks were relatively easy to space accurately, separated by 90 degrees.

A Fourier transform of the disk target series revealed an apparent grouping in fours, i.e. over one disk rotation. Clearly, there was a slight irregularity in the disk rotations which had resulted in this non-uniformity over a cycle.

Thus the possibility arose that the subject's grouping was not self-selected and that the choice of base was either influenced or determined by the number of markers on the disk. The question of influence arises because throughout the previous series of experimental recordings the disk was visible in its entirety. Thus the fact that four marks were clearly present might have influenced the choice. The question of determination refers to the possibility that an irregularity in the inter-coincidence-interval effectively precluded the adoption of any other grouping or the maintenance of equal intervals. The following checks were therefore carried out.

The variability of the disk's period of revolution was measured. Six trial series were recorded, each of one hundred and fifty data points. The mean IBI was set to 769ms (moderato). The mean S.D. of these six series was 4.2ms. The S.D. of that mean of S.D.'s was 0.2ms.

This indicated that the disk fault had not been responsible for determining the group basis, as the disk irregularity was slight, whereas the subject's grouping (see the results) was marked. The difference between the amplitudes of the Fourier transforms of the disk and subject's series was a factor of approximately 2.5.

However, there still remained a possibility that the reason for this difference in degree could lie in the subject's greater variability.

Thus the critical test was to observe whether the grouping base indicated by the number of markers on the disk would invariably be adopted. Any instance of an adoption of a base other than the one suggested would indicate that the subject had not been constrained in making their choice.

Methods

The target series was presented in the main information modalities. Thus there was a visual and an auditory series, a series where both visual and auditory information was present, and an isolation condition, where the subject had to tap with no target series present. These conditions were varied with the number of markers on the disk (for the subject A.M. only). The tempo was not varied, but was set at moderato throughout- this of course meant that with three markers the disk was actually revolving faster, with five, slower. Table one summarises the effect of the number of markers.

Table one

No.Marks	Separation [Degrees]	IBI [msec]	Tempo	Beats:Min	Disk Rev:Min	Degs:sec
3	120	0.769	Mod	78	26.0	165.0
4	90	0.769	Mod	78	19.5	117.0
5	72	0.769	Mod	78	15.6	93.6

Procedural Statement

The subject was introduced to the experiment and told what to do, with no mention of the purpose of the experiment. In each series the subject recorded approximately one hundred and fifty taps. The subject initiated a response sequence at will. The series was terminated by the experimenter after the requisite number of taps had been recorded.

The length of the recording was determined in part by the analysis procedure. Fourier transformation requires that the length of the series of origin be a factor of two. One hundred and twenty-eight taps was within the capabilities of both subjects, but two hundred and fifty-six occasioned boredom and fatigue. The target series was therefore set at one hundred and fifty taps, in order to ensure that there was a sufficient margin over the minimum required amount.

The Interpretation of the Fourier Transforms

In order to understand the results and discussion sections, it is necessary to know a little about the graphs which are referred to and the Fourier transforms they portray. The unit on the x-axis is a unit of one tap. The values on the x-axis are in terms of cycles per tap. Thus:

```
[A] 1:2 cycle per tap = 2 taps per cycle -> a peak at .500
[B] 1:3 cycle per tap = 3 taps per cycle -> a peak at .333
[C] 1:5 cycle per tap = 5 taps per cycle -> a peak at .200
```

In these examples, the inter-beat-intervals might look like this:

```
[A] or 2:4 time
+         .         .         .         .
+
+       .         .         .         .
+
++++++++++++++++++++++++++++++++++++++++++++++++++
[B] or 3:4 time
+         .         .         .         .
+        .         .         .         .
+       .         .         .         .
++++++++++++++++++++++++++++++++++++++++++++++++++
or [B] might look like this
+         .         .         .         .
+
+       ..        ..        ..        ..
++++++++++++++++++++++++++++++++++++++++++++++++++
```

It is important to remember these are contributions to the total. A 2:4 and a 3:4 occurring together might look like this in the pre-transform series:

```
+            .
+        ...                  [2:4 & 3:4 resultant]
+       .    .
++++++++++++++++++++++++++++++++++++++++++++++++++
```

And factorise out to give both series:

```
+        . . .
+                             [a 2:4]
+       . . .
+
+
+          . .
+                             [a 3:4]
+       .. ..
+
++++++++++++++++++++++++++++++++++++++++++++++++++
```

The Y-axis is an interval scale, on which is plotted the amplitude of each transformed series. Values on the Y-axis show the relative contribution of each component frequency. Thus it is possible to compare directly the contribution of frequencies both within and across different transforms.

Finally, note that if there is a regular 2:4 rhythm, for example, with IBI's long-short long-short, and if this should switch to a short-long short-long, the peak in the transform will shift downwards from the .500 to somewhere between the .250 (4:4) and the .500 (2:4). The presence of harmonics at multiples of the basic frequency then becomes essential in the interpretation of results. Harmonics have two possible sources. Firstly, they may be artificial. With a very regular series, with pulses grouped in a relatively invariant manner, the systematic difference between, for example, a triangular waveform and the sinusoidal which the transform procedure fits occurs at a regular frequency, so appears as a harmonic. Secondly, harmonics may be real. With a subject, a harmonic is far more likely to be a genuine grouping of, for example, two 2:4's (which would give a secondary peak at .5) within a 4:4 bar (with the main peak at .25).

The Fourier transforms of each experimental series should be examined in conjunction with the graphs of the IBI's, grouped according to the base revealed in the appropriate Fourier transform. Each point represents the mean IBI and is plotted with the standard error. The criterion adopted was that when means are separated by more than one standard error (S.E.), the grouping base provides unequivocal evidence for a grouping effect. The greater the separation in relation to the S.E.'s, the more marked the grouping. Where no grouping base was immediately obvious from the Fourier transform, or where additional peaks in the transformed series suggested a multiple choice of base, the IBI's were grouped on bases corresponding to both of the two strongest contributions and the profiles compared. If a Fourier transform reveals a clear contribution at a given frequency, then it is necessarily the case that the IBI's will reflect this finding.

Note that is not possible to compare the actual pattern within the group across trials, as the first data point in each series was termed the "first" in each bar.

Subjects.

This set of experiments was run with one principal subject, A.M. The preference for grouping base was found to be highly idiosyncratic and was therefore not compared across subjects. Subject T.S. was asked to replicate only one set of trials, in order to confirm that the grouping phenomenon itself would emerge with any subject.

Results

The results for the principal subject, A.M., will be presented first.

[1] With the visual series the disk was visible but there was no auditory sequence present.

[1a] With three markers on the disk, there is some indication of a tendency to group in threes, as evidenced by the peak at .312 in figure 7.1. The fact that this peak is a little below the .333 that would be produced by a dominant grouping in threes could have resulted from some variation as to which beat was the "first" in the "bar". If the internal dynamic of the grouping manifested in different length IBI's, then a variation in the absolute sequencing would have the effect of apparently diminishing the contribution in the transform. If, for example, the subject was grouping in threes, then missed a beat, then grouped in threes again, the phase shift would apparently weaken that contribution.

The effect however is relatively weak and the peaks only just above general noise level. Figure 7.2, however, demonstrates that the grouping to base three was sufficient to distinguish the IBI's. The first interval in the "bar" was short, the second long, the third midway.

[1b] With four markers on the disk, there is a peak at .227 in figure 7.3. This is most probably a grouping in fours, with the X-axis value reduced by variation of the internal dynamic of the

grouping. Note also the peak at .125, the harmonic. This is further evidence for the primary grouping into fours. A regularity around four beats, when the 4:4 bars are themselves being grouped in twos, will give rise to a regularity around eight. This could be interpreted, according to the theoretical framework, either as evidence of a superordinate level of "planning" or an added frequency from the driver or inherent to the oscillatory system.

There is a clearer separation here than in the last example, the peaks being distinct above the level of noise. The separation is also seen in figure 7.4, the first and third are made long, the second and fourth short.

[1c] With five markers on the disk, the dominant grouping in figure 7.5 is quite clearly a 2:4 (note the peak at .500), with a secondary contribution at .250 which, as a 4:4, probably reflects the same effect.

This latter result is clear evidence that the subject can adopt a grouping other than that represented on the disk. As an additional check, analysis of the IBI's in terms of grouping base five as well as four (see figures 7.6 and 7.7) shows that the base five does not discriminate between the IBI's, while with base four there is clear separation.

[2] With the auditory series the subject kept both eyes closed, so the disk was not visible. The subject then followed the auditory series alone.

[2a] With three marks on the disk, the subject's data (figure 7.8) shows a very clear three-beat grouping. Figure 7.9 shows the pattern of discrimination. The first in the bar was very short, the second longer, the third longest.

[2b] With four marks on the disk the subject, as can be seen in figure 7.10, emphasised 4:4 part of the time (peaks at .445 and at .484), with the alternation of 2:4 (evidenced in the dominant contribution at .250) within a 4:4 grouping giving rise to the reduction of the .445 and .484 from the .500 and possibly also to the peak at .305. Figure 7.11 shows the pattern, shortest to longest throughout the "bar".

[2c] With five on the disk, the subject (see figure 7.12) gets a fairly convincing peak at .250 (four in the bar) and one at .453 which might reflect at 2:4 (which would peak at .500) within the 4:4 with some variations. Figures 7.13 and 7.14 reinforce this conclusion. These show, respectively, grouping to base five, which reveals some distiction, and grouping to base four, which is more marked.

[3] In the third series both visual and auditory series were present.

[3a] With three on the disk the subject's transform does not show grouping by threes (see figure 7.15). There is a high point at .336 (reveals 3:4), it ranks approximately equal with points at .250 (4:4) and .445 (possible alternation between 4:4 and 2:4 with 3:4).

The main peak is at .141. This could conceivably be a 7:4, it might also be a .125 (8:4) with some moderating variation. The main point is that 3:4 is not the dominant grouping. The analysis to bases of three and four (figures 7.16 and 7.17 respectively) proved both viable in that both revealed differences in the IBI's, but the separation between longest and shortest intervals was greatest when grouped to base four.

[3b] With four on the disk, the subject (see figure 7.18) has also adopted a 4:4 grouping. Plotting the IBI's (figure 7.19) confirms the clear separation. The pattern here is slow- medium- quick-medium.

[3c] With five on the disk, the subject's peak (see figure 7.20) near .400 shows that there is some 5:4 influence, the point near .200 offers slight support, other peaks at .461 and .437 and .273 show that other, alternate groupings were clearly present in addition. Figures 7.21 and 7.22 show that both bases four and five adaquately discriminate between the IBI's.

[4] The "no target" series. Here the subject tapped alone, with no target series present, trying to replicate the same periodicity that had been presented in the immediately prior recordings.

[4a] With three on the disk, figure 7.23 shows peaks at .414, .102, .250, and .352 in order of lessening importance. The .414 might be interpreted as .400 and as such evidence of a 5:4, but in the absence of a peak at .200 this is not supportable. It may even be a

2:4 which existed for part of the time only and hence was reduced from .500. There is some hint of a .250 (4:4), which might support that latter interpretation. On the other hand, The .102 might be a harmonic of a 5:4. Figures 7.24 and 7.25 show analyses to base four and five respectively. Analysis to base four shows a minimal discrimination, but analysis to base five shows none. Overall, therefore, different groupings were probably present for different portions of the time. Figure 7.26 shows that in this condition, unlike the others, there was an absence of unidirectional drift away from the mean IBI.

[4b] With four on the disk, figure 7.27 shows that the majority of peak points are at low X-axis values. This means a slow drift in the subject's mode of response, from fast to slow or vice-versa, which has swamped other contributions. In this case the direction was from fast to slow (see figure 7.28). One smaller peak at .250 indicates that some 4:4 survived. This was just enough to ensure discriminability of IBI's (see figure 7.29).

[4c] With five on the disk, figure 7.30 shows no peaks whatsoever save at low X-axis values. There was no coherent grouping, only a slow drift. Figure 7.31 shows this drift, a gradual slowing. Analysis to bases four (figure 7.32) and five (figure 7.33) shows that no pattern emerges for either base.

In two out of three trials, when A.M. was asked to reproduce a tempo after some delay, he produced a series around 10% slower than the target tempo. The exception was the suggested base three condition. With base four the series was 10.8% slower, with base five 11.2% slower. In the latter two conditions a large drift swamped the grouping contrbutions. In the base three condition, where the series held relatively steady, and close to the correct mean IBI, various contributions could be seen, but there is no clear result.

Replicating subject's results.

The subject T.S.'s results were as follows.

[1] With the visual series the subject showed a clear 4:4 grouping. There was a clear peak at .227. See figure 7.34.

[2] With the auditory series the main peak, at .461, indicated a 2:4 beat. See figure 7.35.

[3] When both visual and auditory series were present the largest peak was at .195, indicating a 5:4. See figure 7.36.

[4] In the no-target condition no clear grouping could be distinguished, as the low-value drift was so great. See figure 7.37.

Summary of Results

Subject A.M.

A.M. tends to adopt a 4:4. Where there were four markers on the disk, a 4:4 was the preferred choice in all cases.

Where there were three markers, in only one out of four conditions was a clear 3:4 adopted. In another of the conditions, a 3:4 was arguably present, but here the effect was considerably diluted. In two out of the four conditions there was a mix of groupings, with some 4:4 in both cases (and even a hint of five in a bar in one).

Where there were five markers the subject did not generally adopt a five in a bar. The prevailing mode was 4:4. In one out of the four conditions some 5:4 was present in addition to some hint of 4:4.

Table two summarises the results.

Table two

Subject A.M.

Number on disk	Information present	Definite Grouping?	Base selected?	Same as suggested base?
three	visual	weak but yes	three	yes
three	auditory	yes	three	yes
three	both	yes	mixed	possible (some four)
three	no target	yes	mixed	no (some four and five)
four	visual	yes	four	yes
four	auditory	yes	four or two	yes
four	both	yes	four	yes
four	no target	---	---	---
five	visual	yes	four	no
five	auditory	yes	four or five	possible
five	both	yes	mixed (some five)	possible
five	no target	---	---	---

Subject T.S.

Number on disk	Information present	Definite Grouping?	Base selected?	Same as suggested base?
four	visual	yes	four	yes
four	auditory	yes	two	no
four	both	weak but yes	five	no
four	no target	---	---	---

T.S.'s results confirm that a grouping base can be identified in every condition. All T.S.'s data was recorded with four markers on the disk. A 4:4 was adopted once, and a 2:4 once, but a 5:4 also appeared, which further confirms that the base adopted is of the subject's choosing.

Conclusions

[1] In almost every case grouping was observed.

[2] Neither subject's choice of grouping was determined by the layout of the disk, although the suggested grouping was on some occasions adopted for some or all of the time.

[3] There was an overall preference for 4:4.

[4] When the preferred choice of base and the number of marks on the disk were mutually compatible the clearest peaks emerged, indicating the most pronounced grouping effect.

FIGURE 7.1

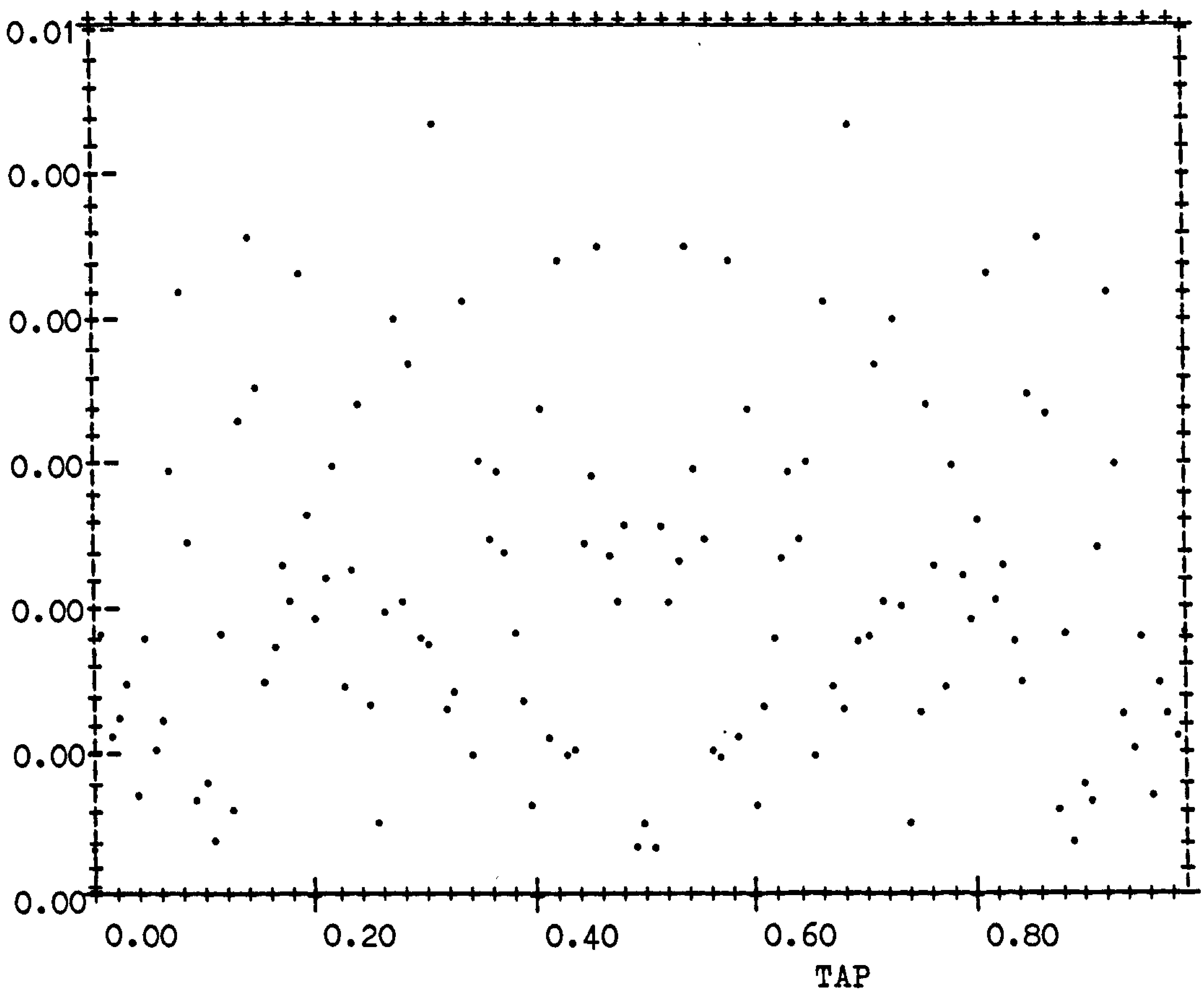


Figure 7.2
Inter beat intervals
Means and S.D.'s

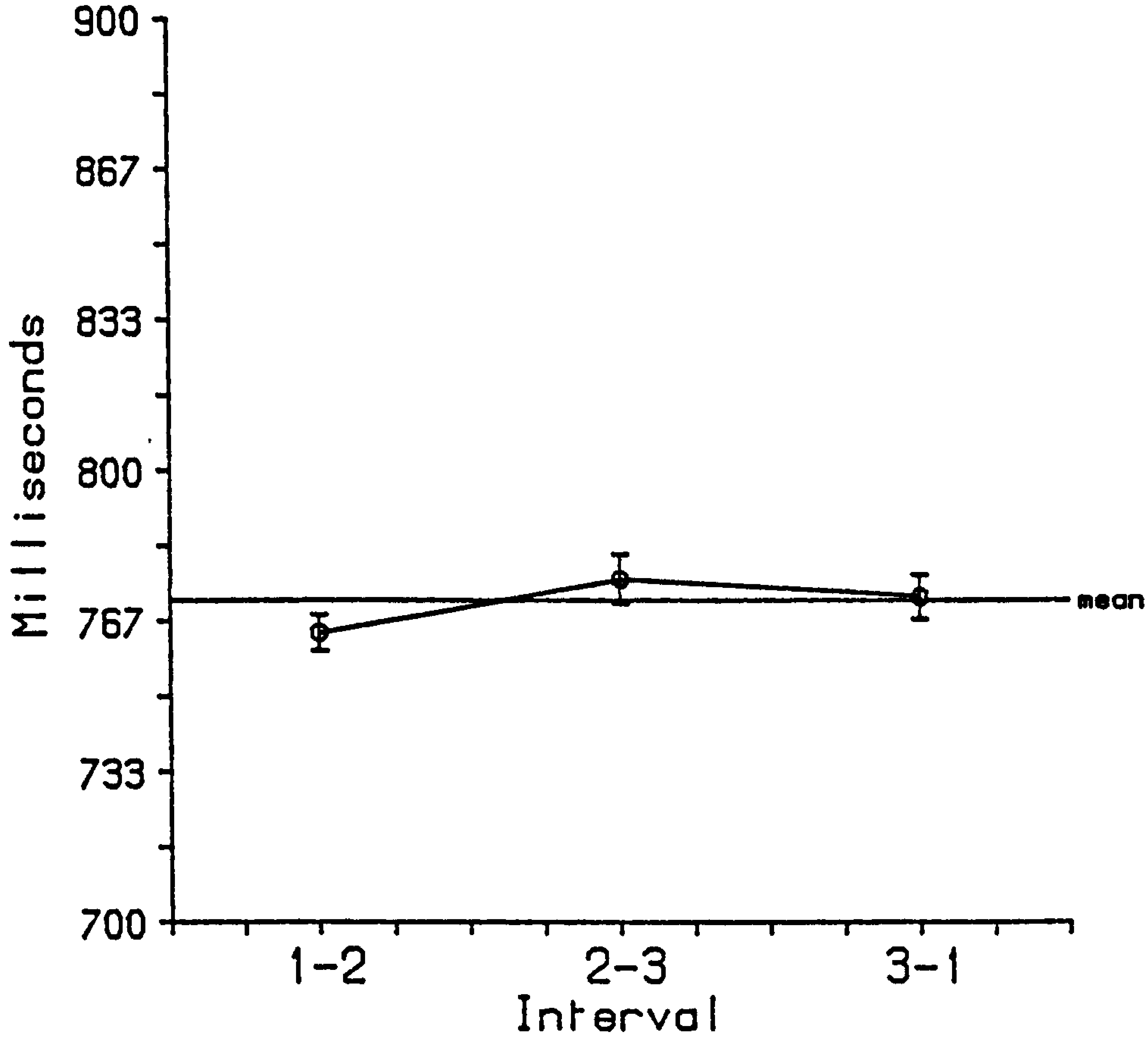


FIGURE 7.3

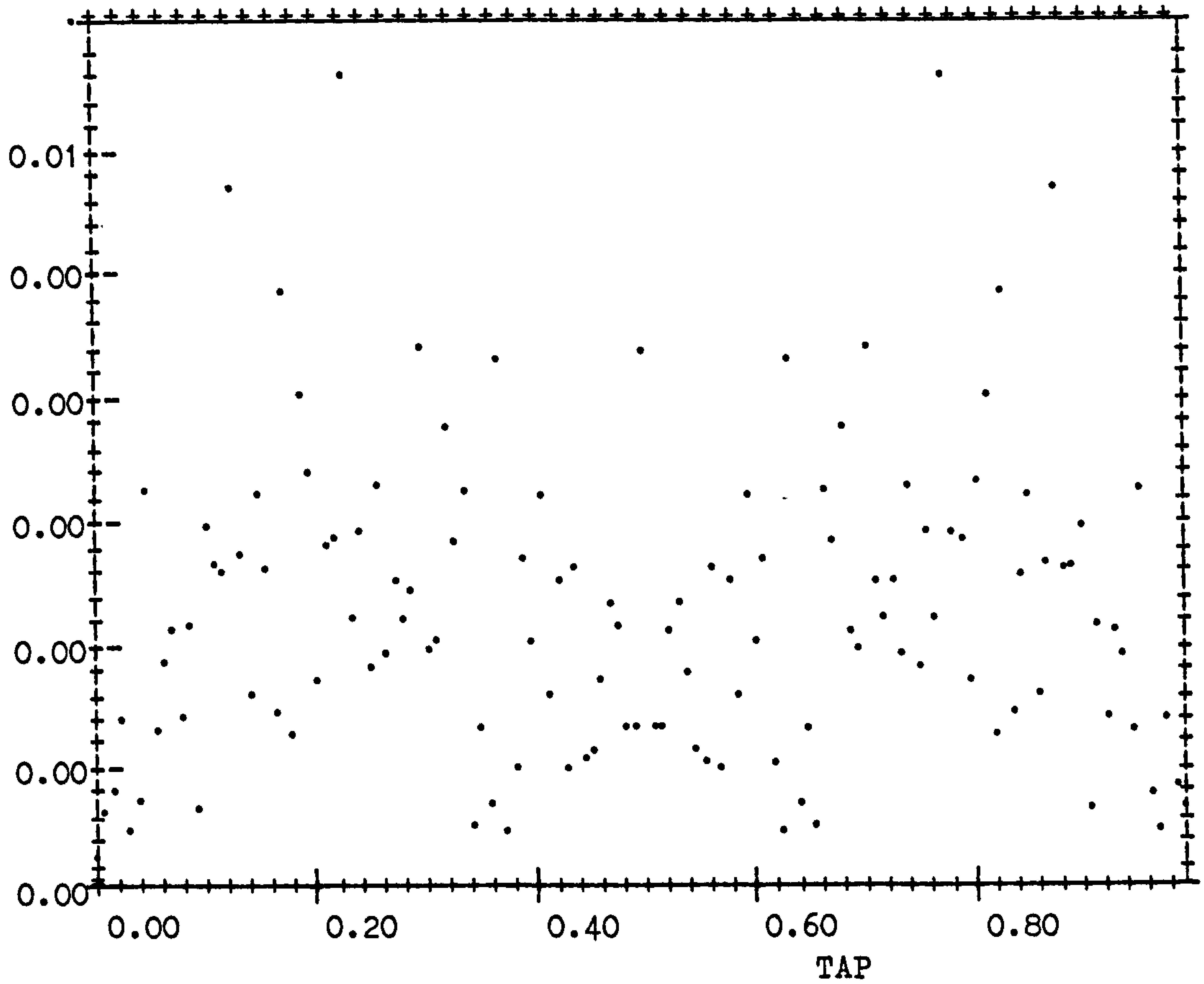


Figure 7.4
Inter beat intervals
Means and S.D.'s

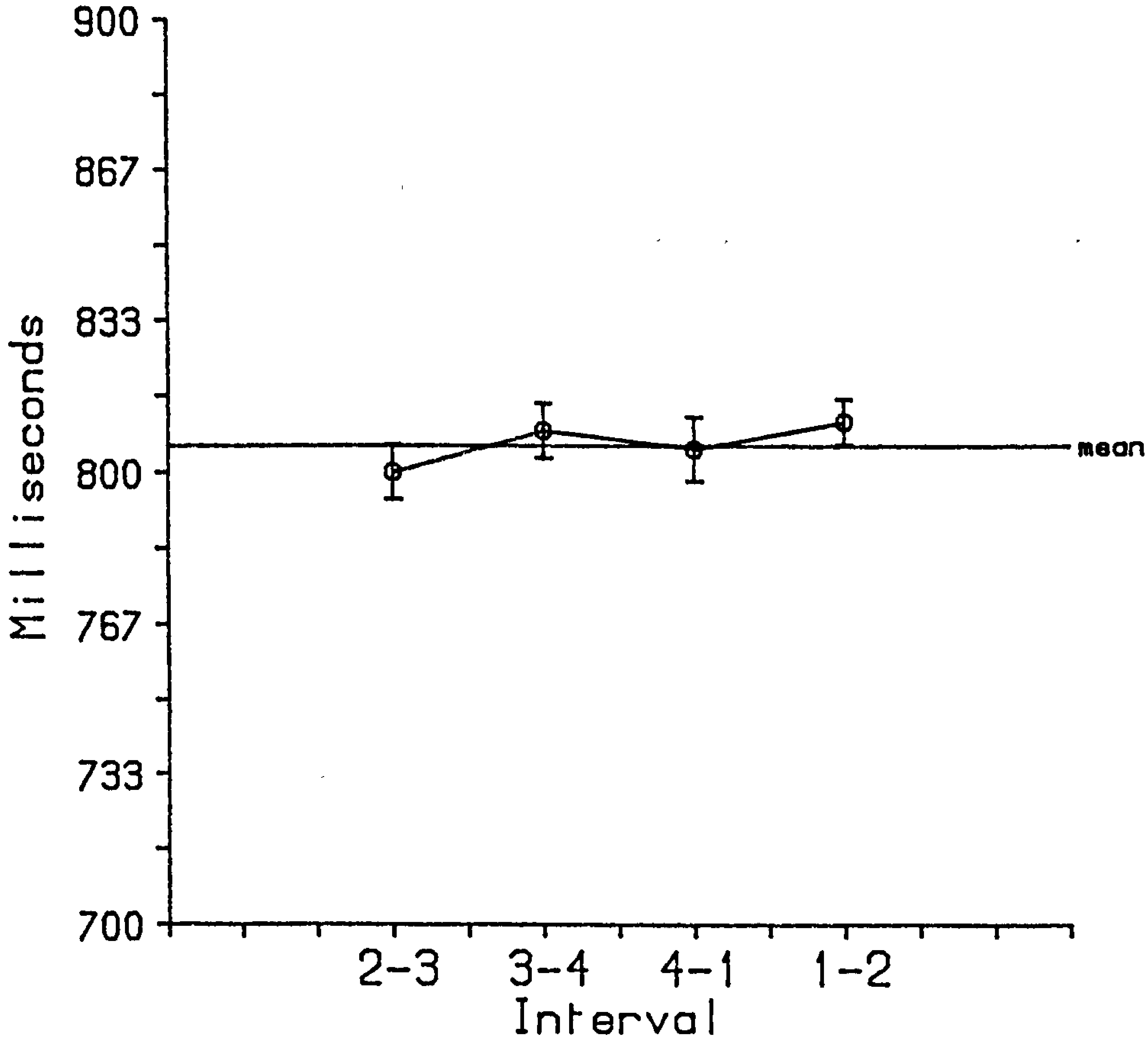


FIGURE 7.5

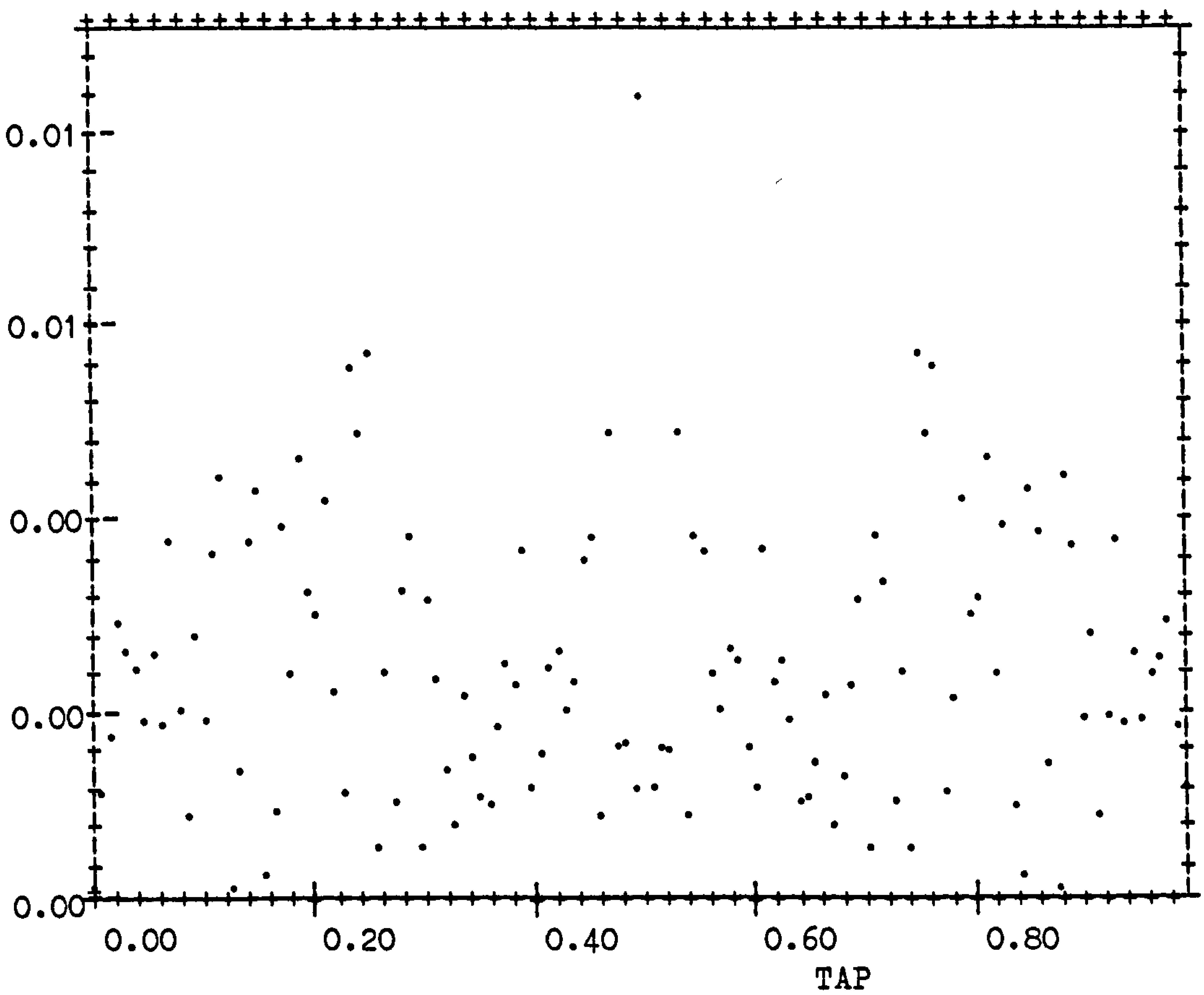


Figure 7.6
Inter beat intervals
Means and S.D.'s

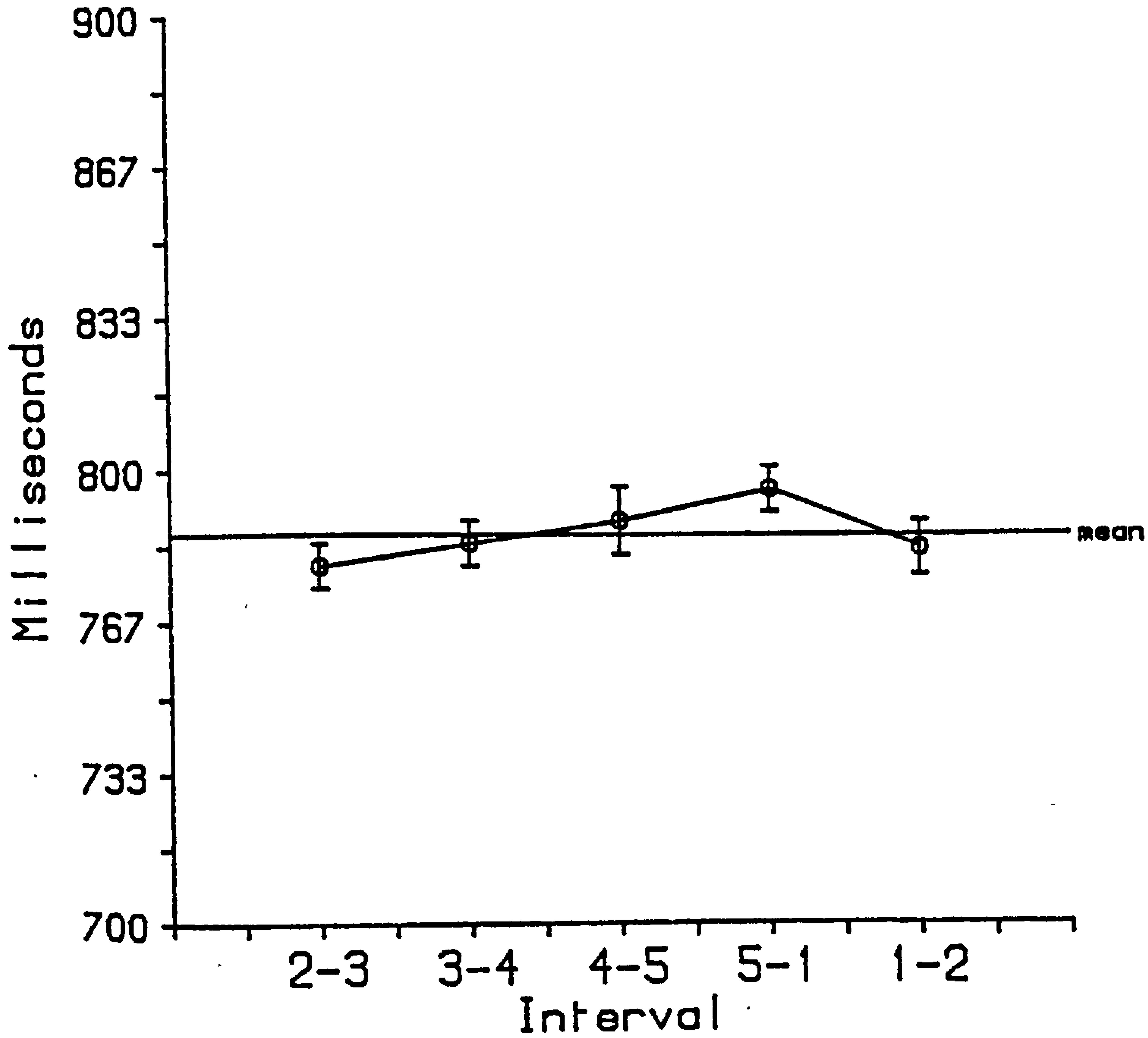


Figure 7.7
Inter beat intervals
Means and S.D.'s

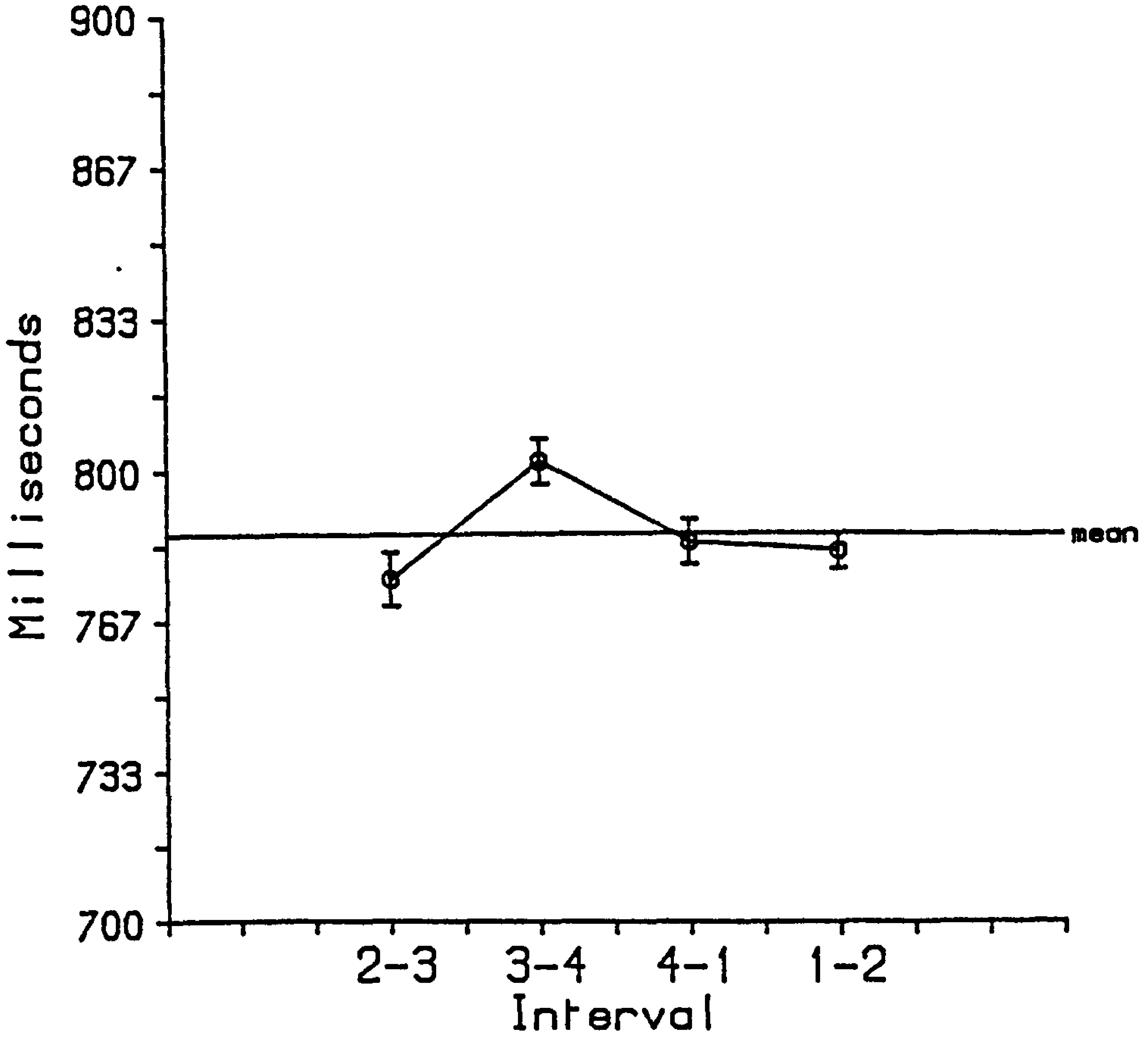


FIGURE 7.8

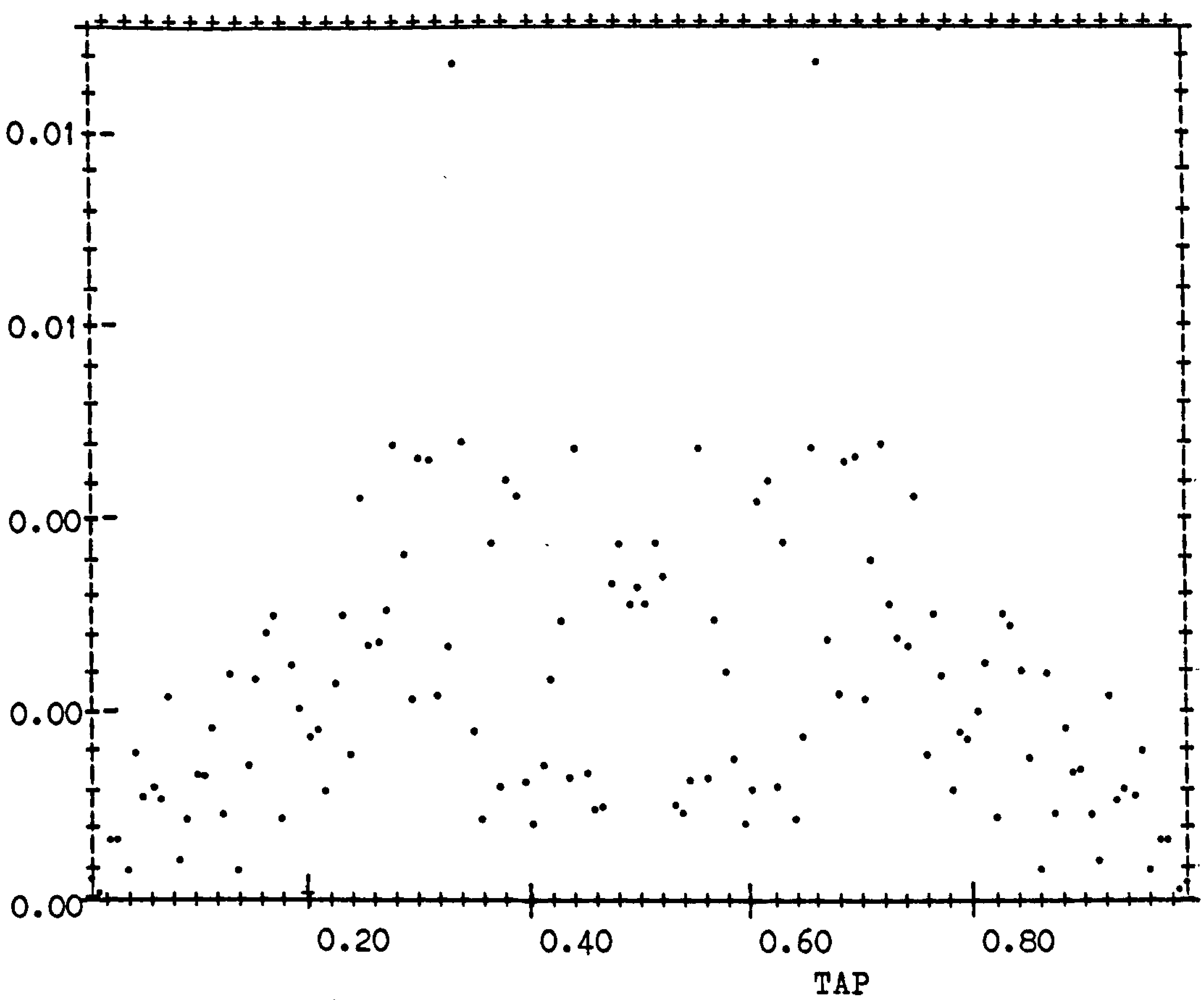


Figure 7.9
Inter beat intervals
Means and S.D.'s

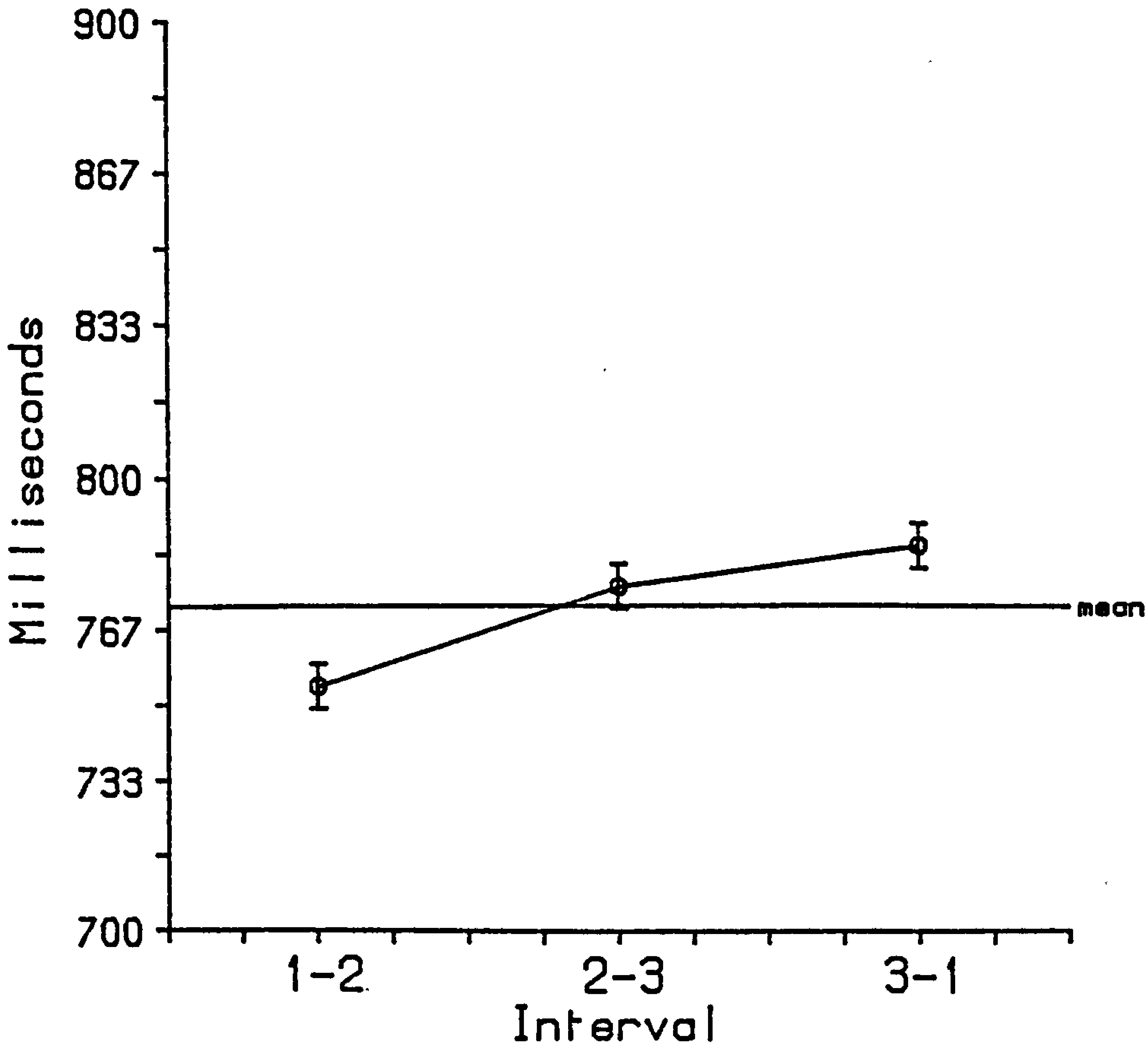


FIGURE 7.10

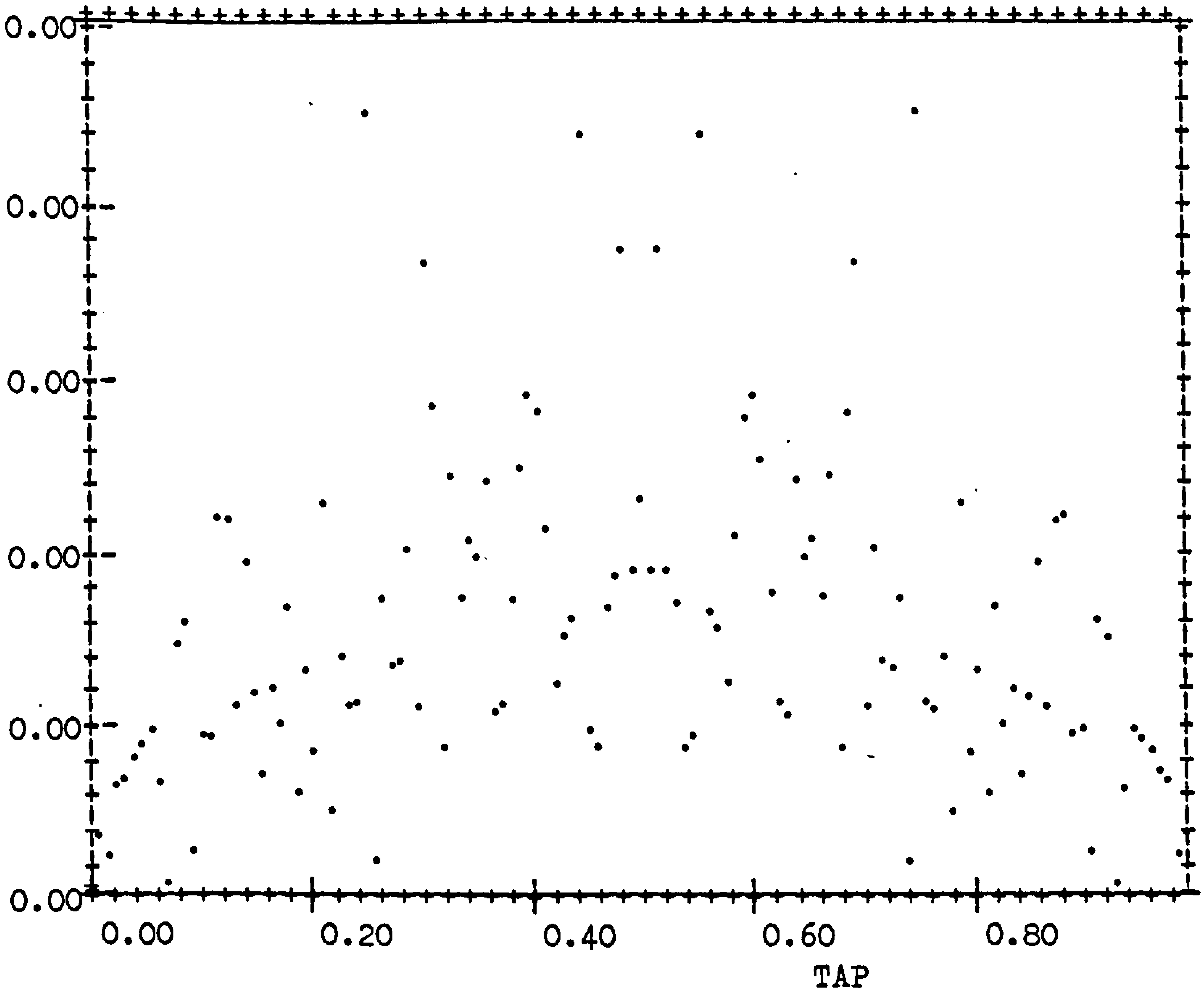


Figure 7.11
Inter beat intervals
Means and S.D.'s

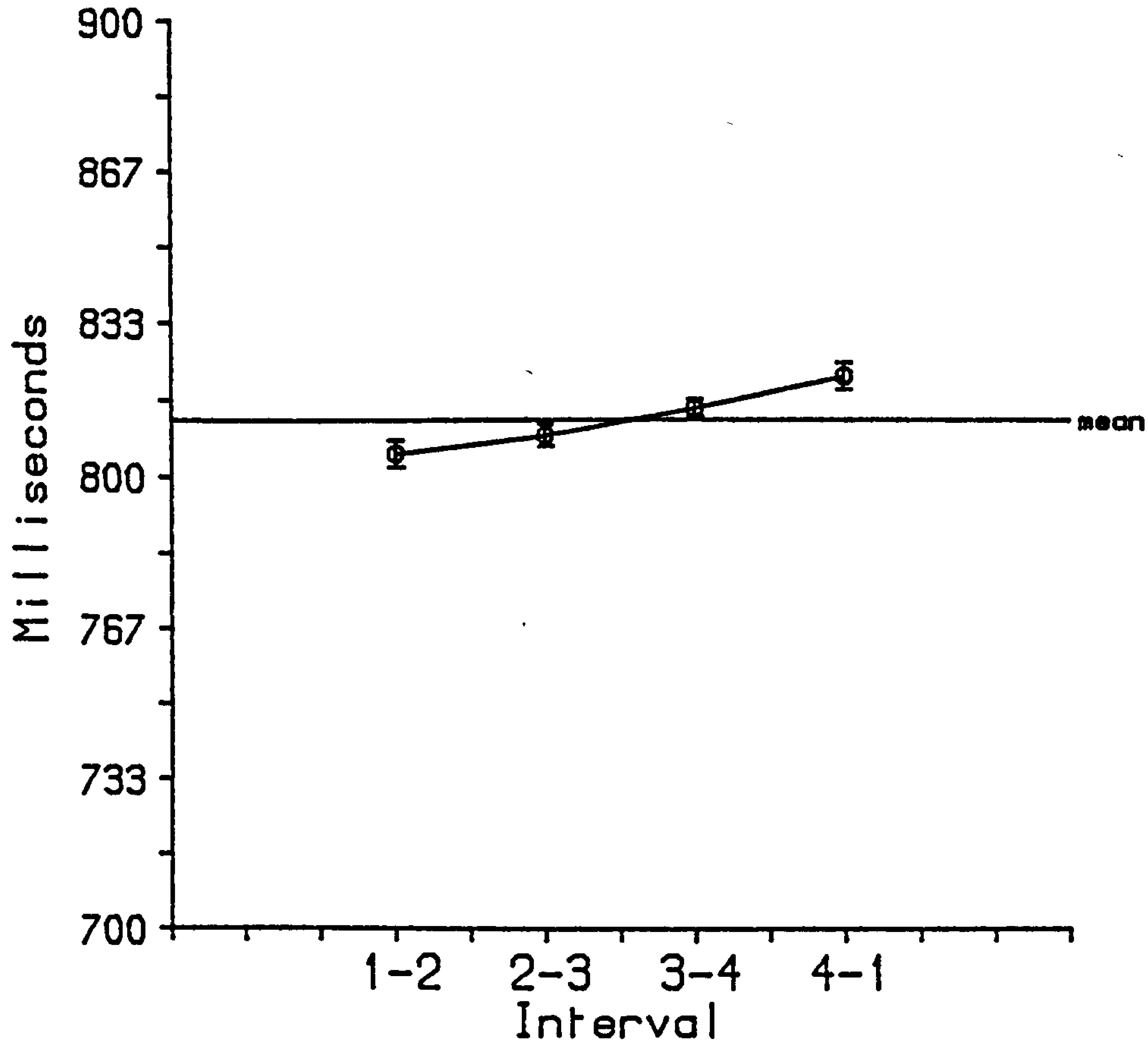


FIGURE 7.12

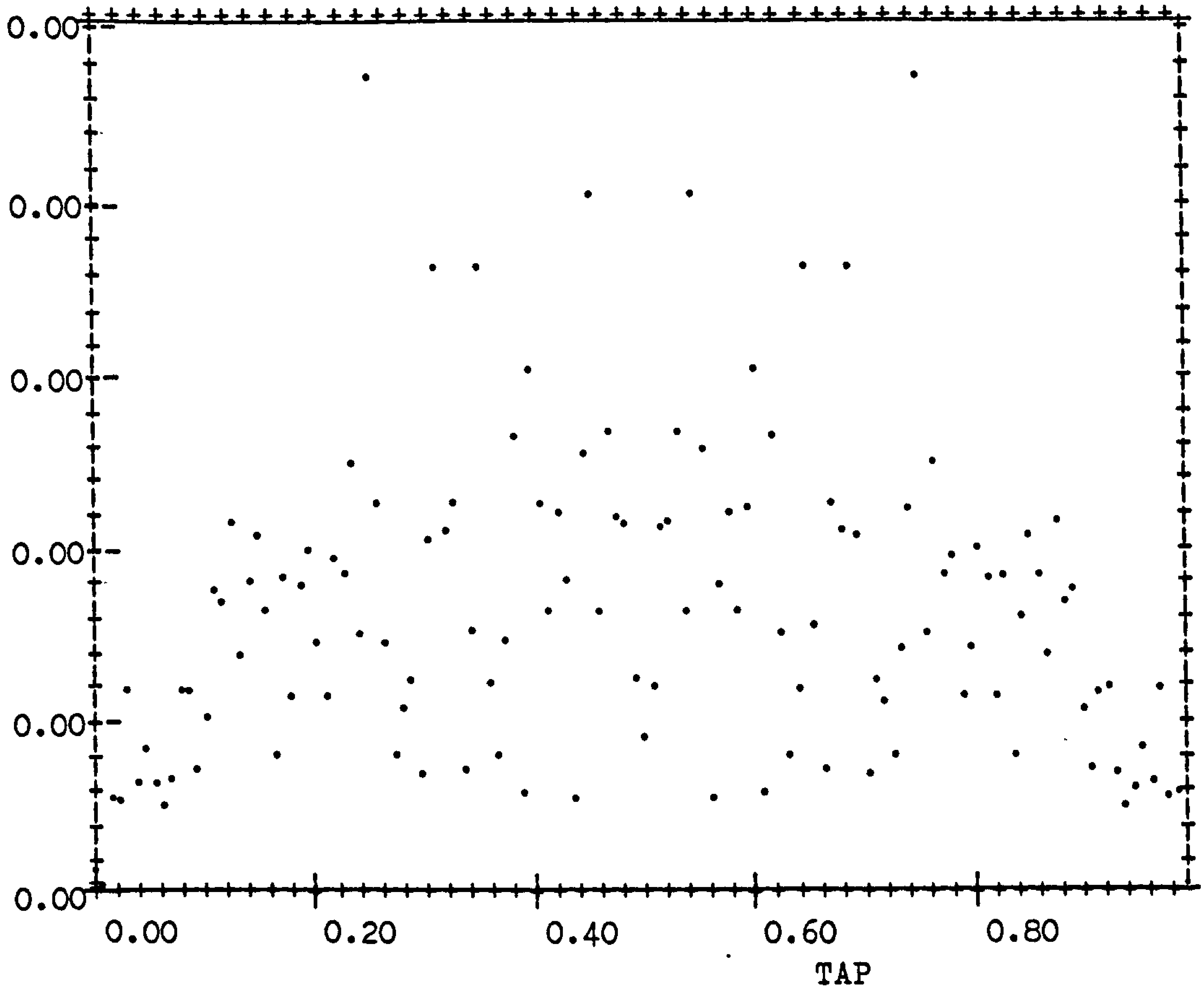


Figure 7.13
Inter beat intervals
Means and S.D.'s

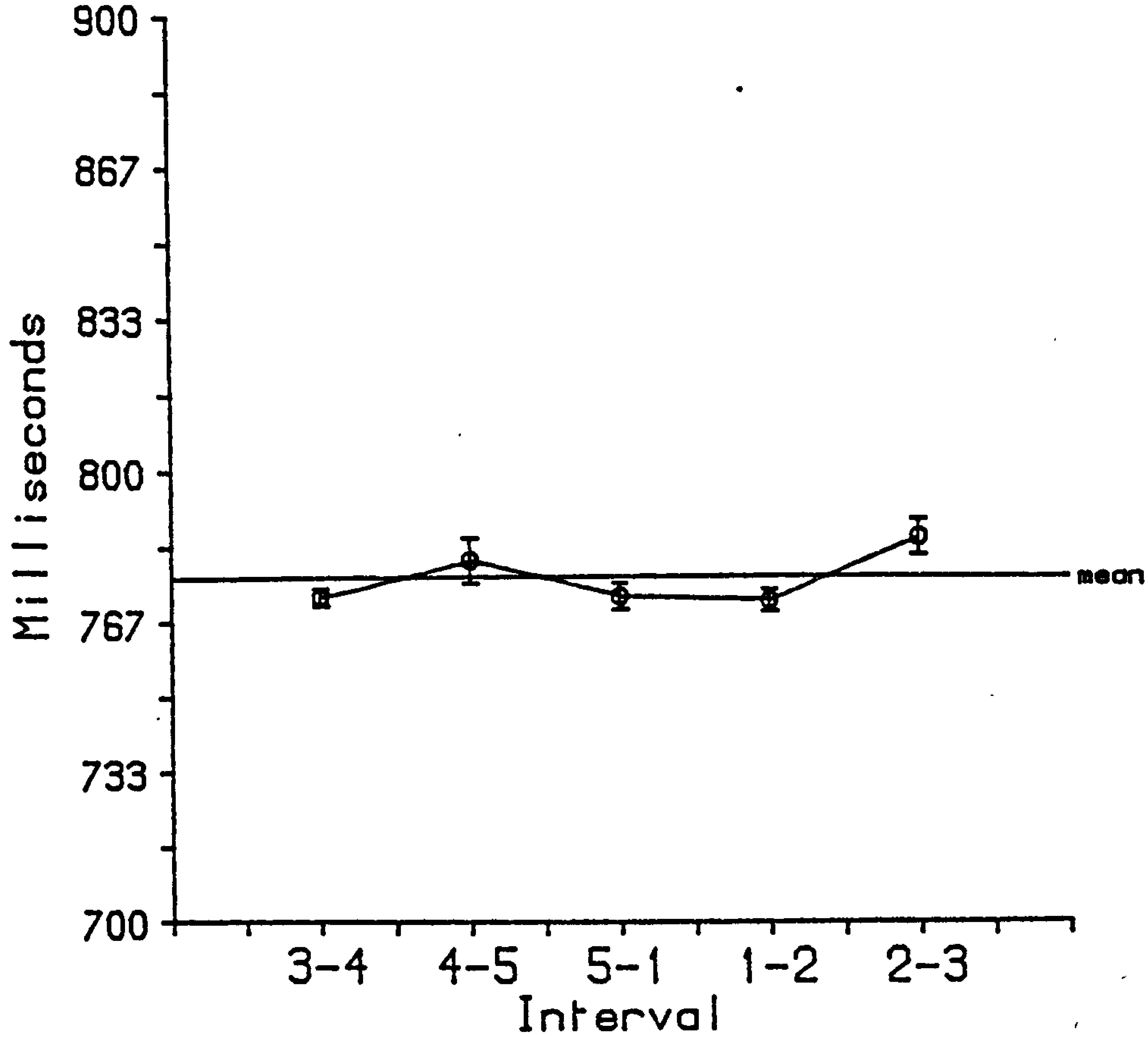


Figure 7.14
Inter beat intervals
Means and S.D.'s

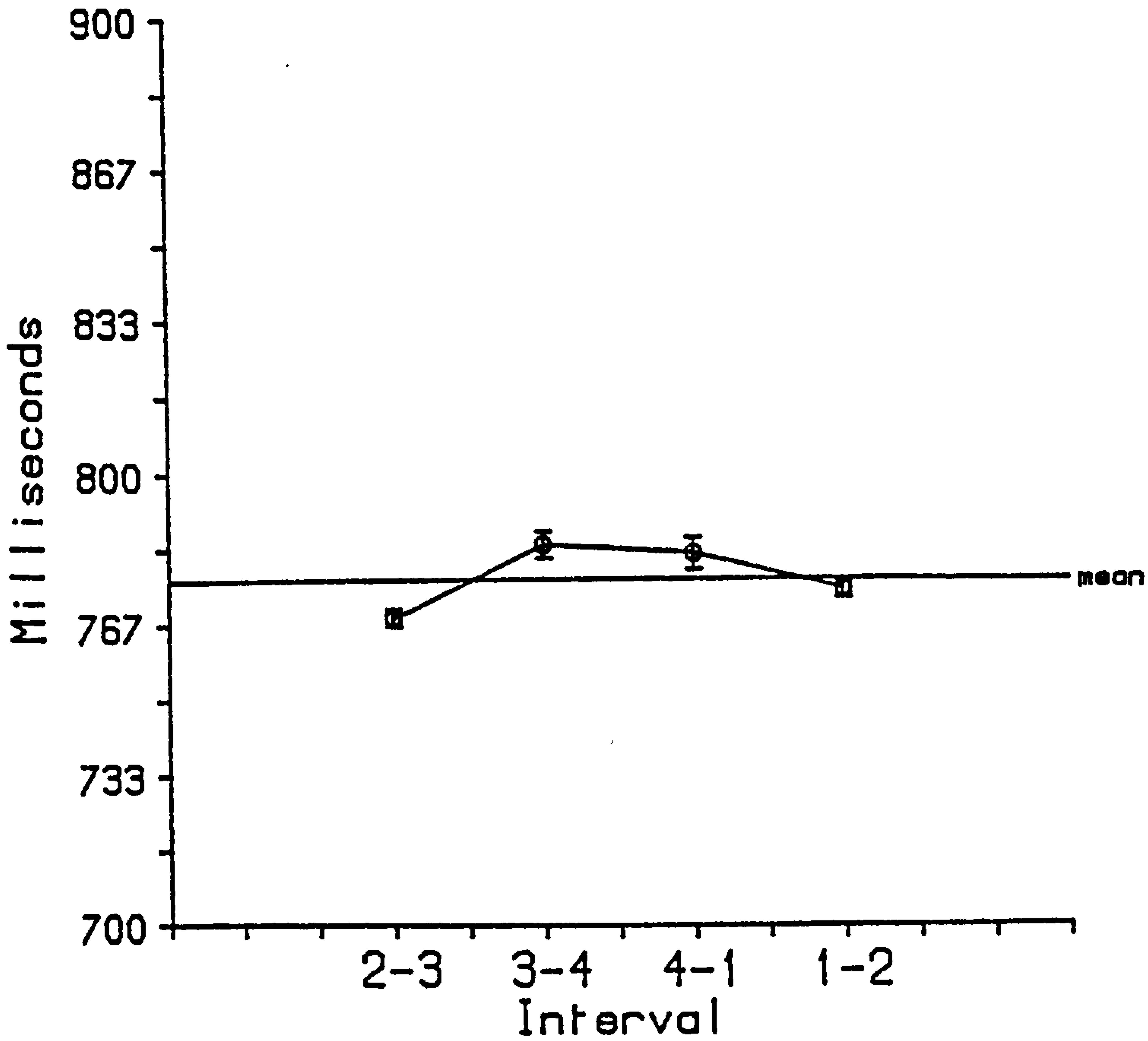


FIGURE 7.15

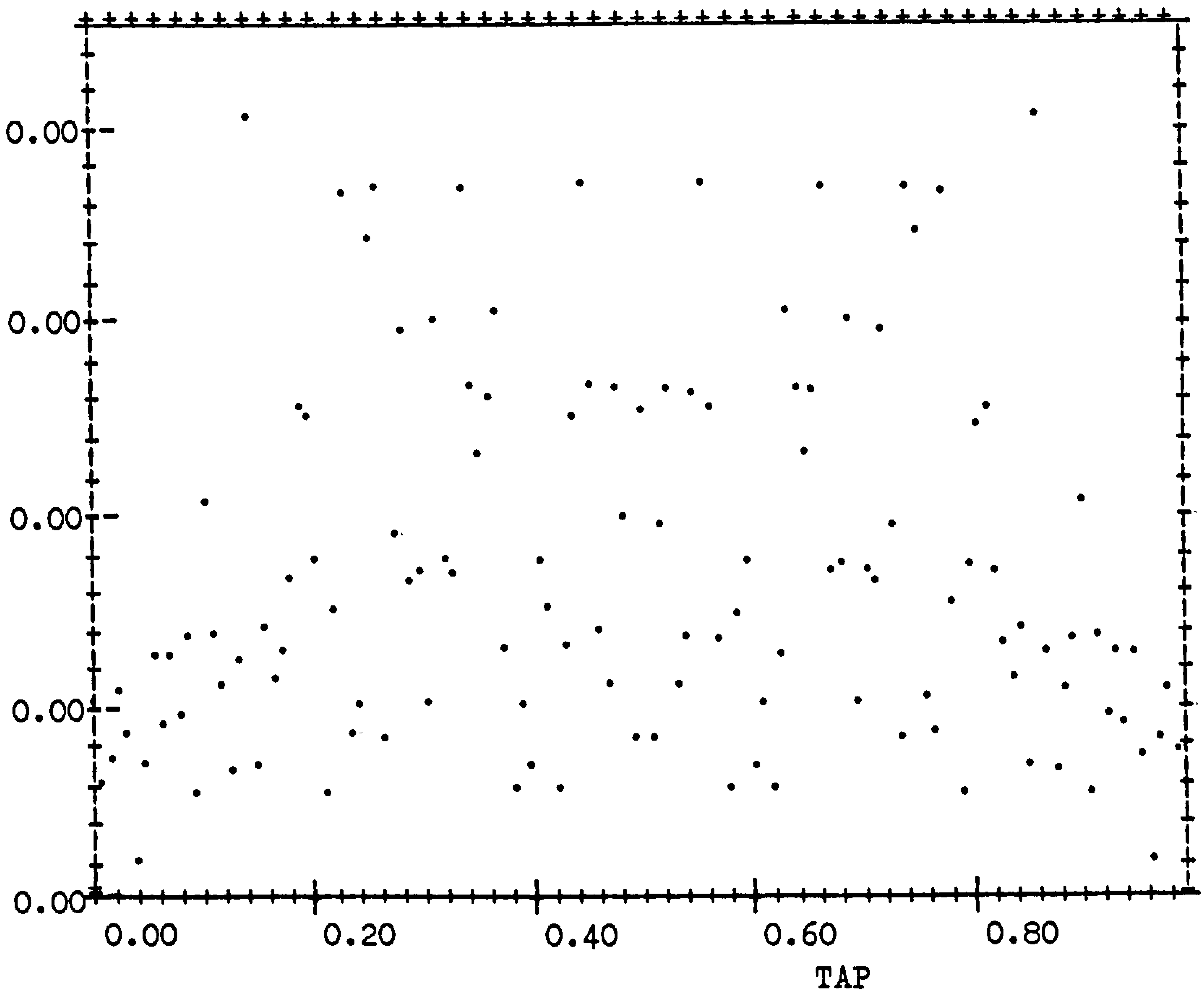


Figure 7.16
Inter beat intervals
Means and S.D.'s

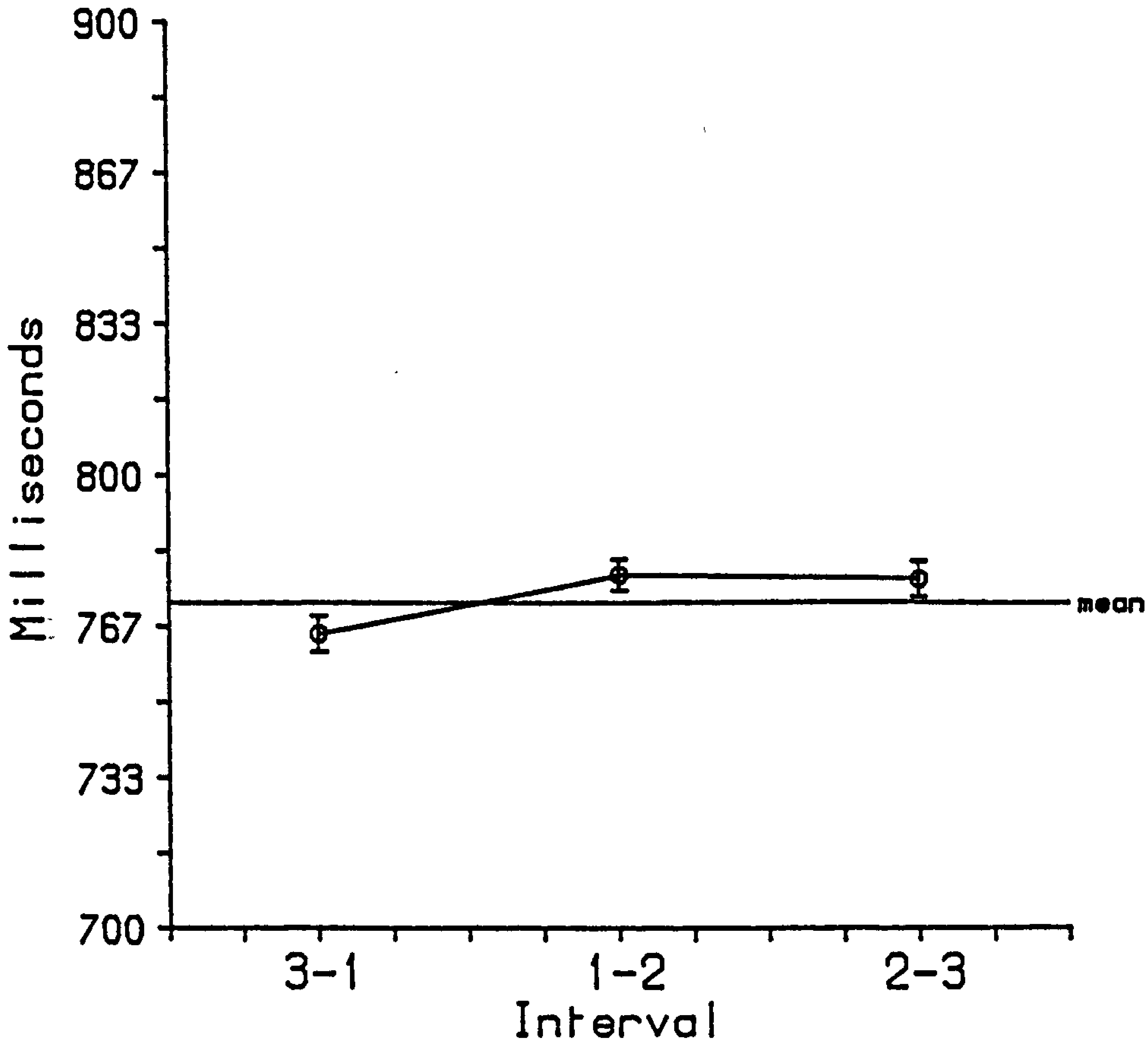


Figure 7.17
Inter beat intervals
Means and S.D.'s

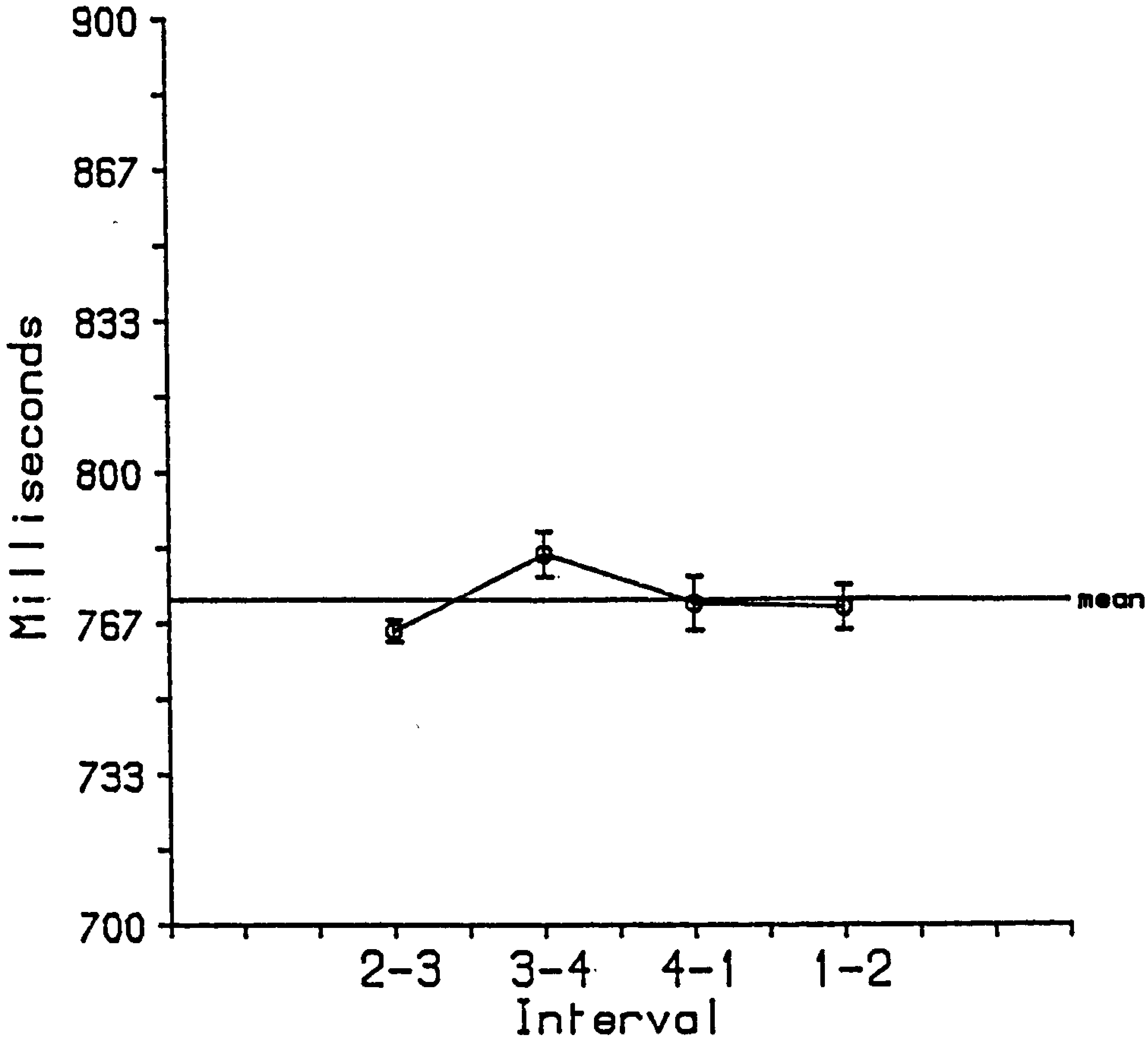


FIGURE 7.18

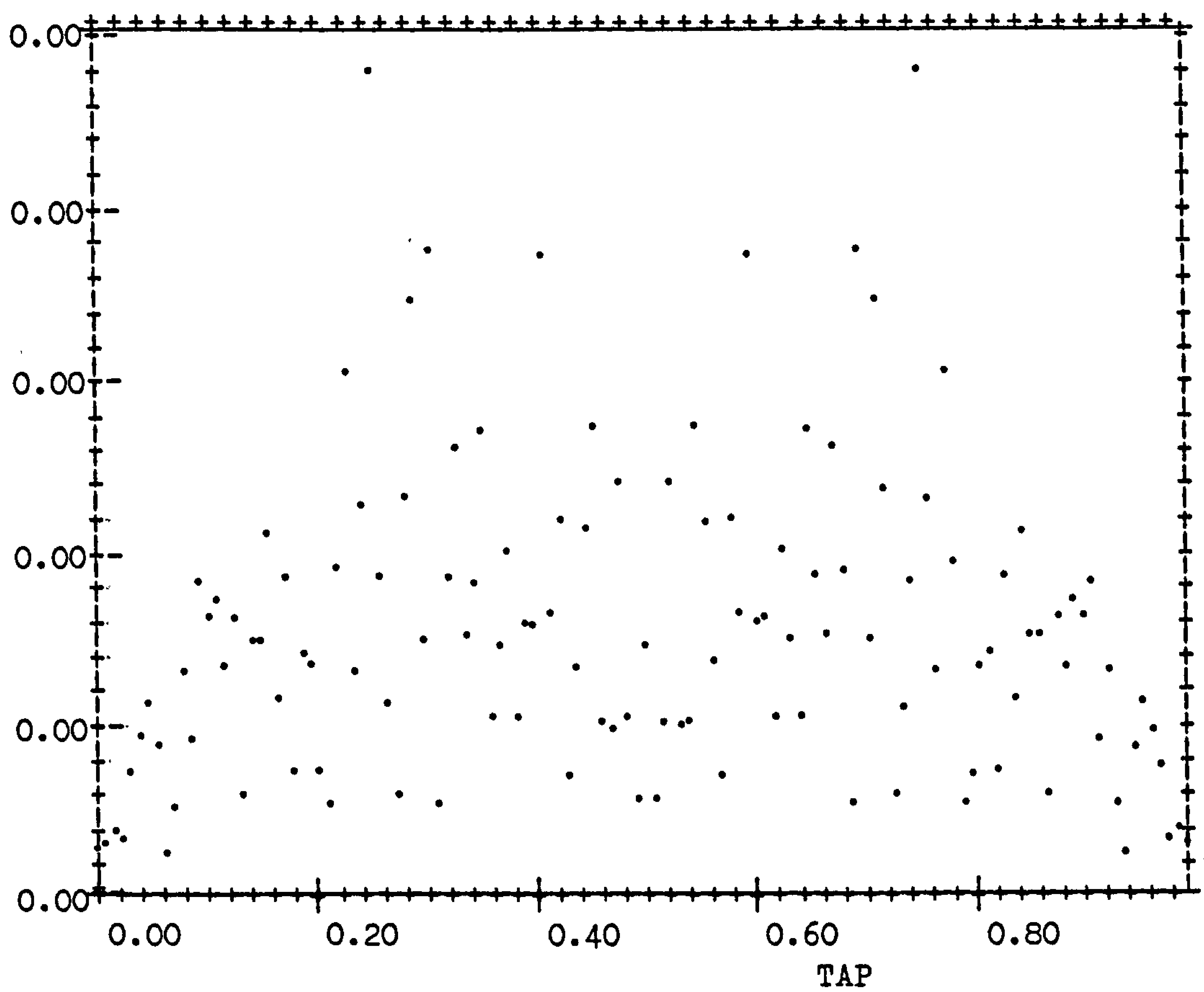


Figure 7.19
Inter beat intervals
Means and S.D.'s

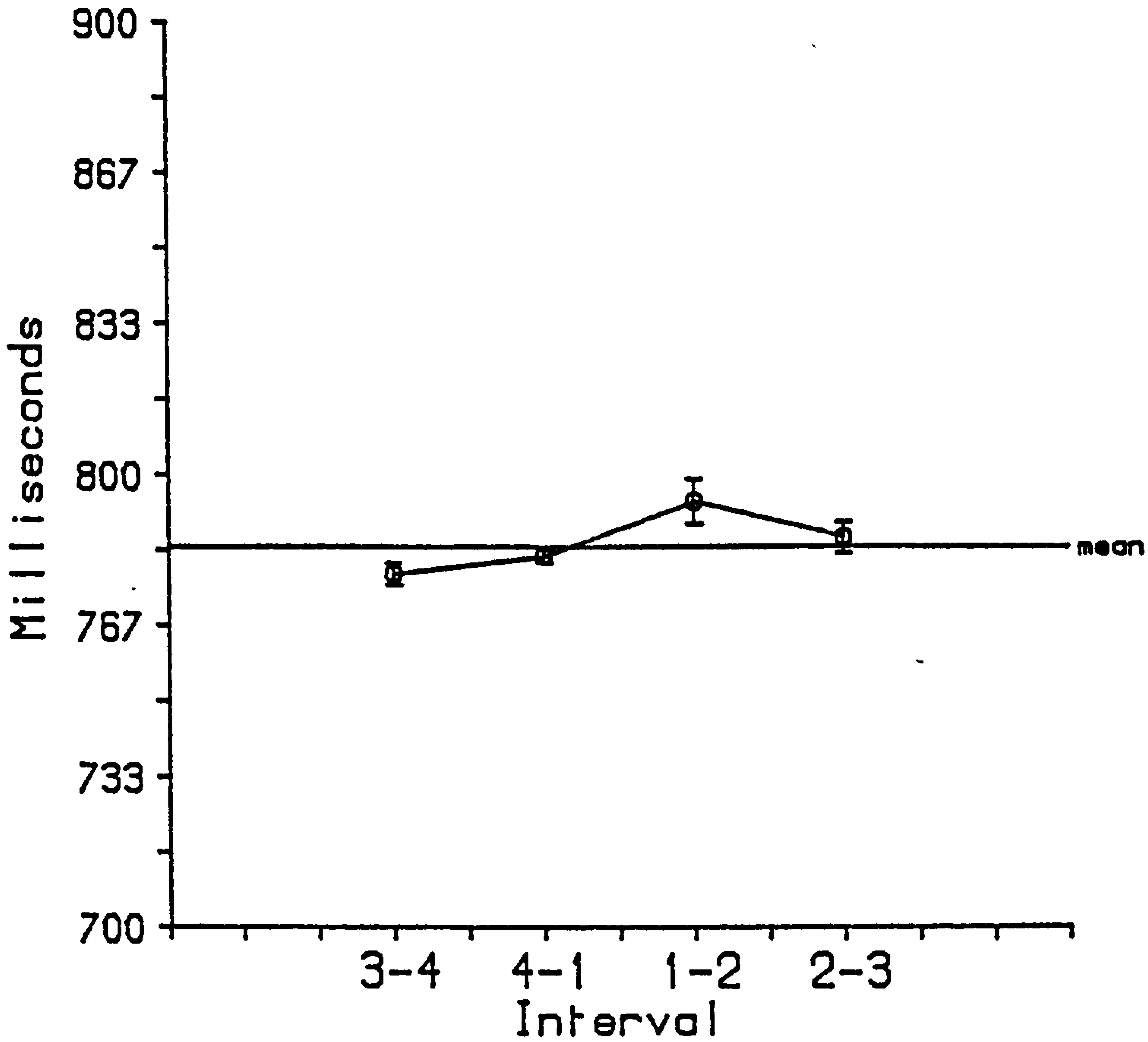


FIGURE 7.20

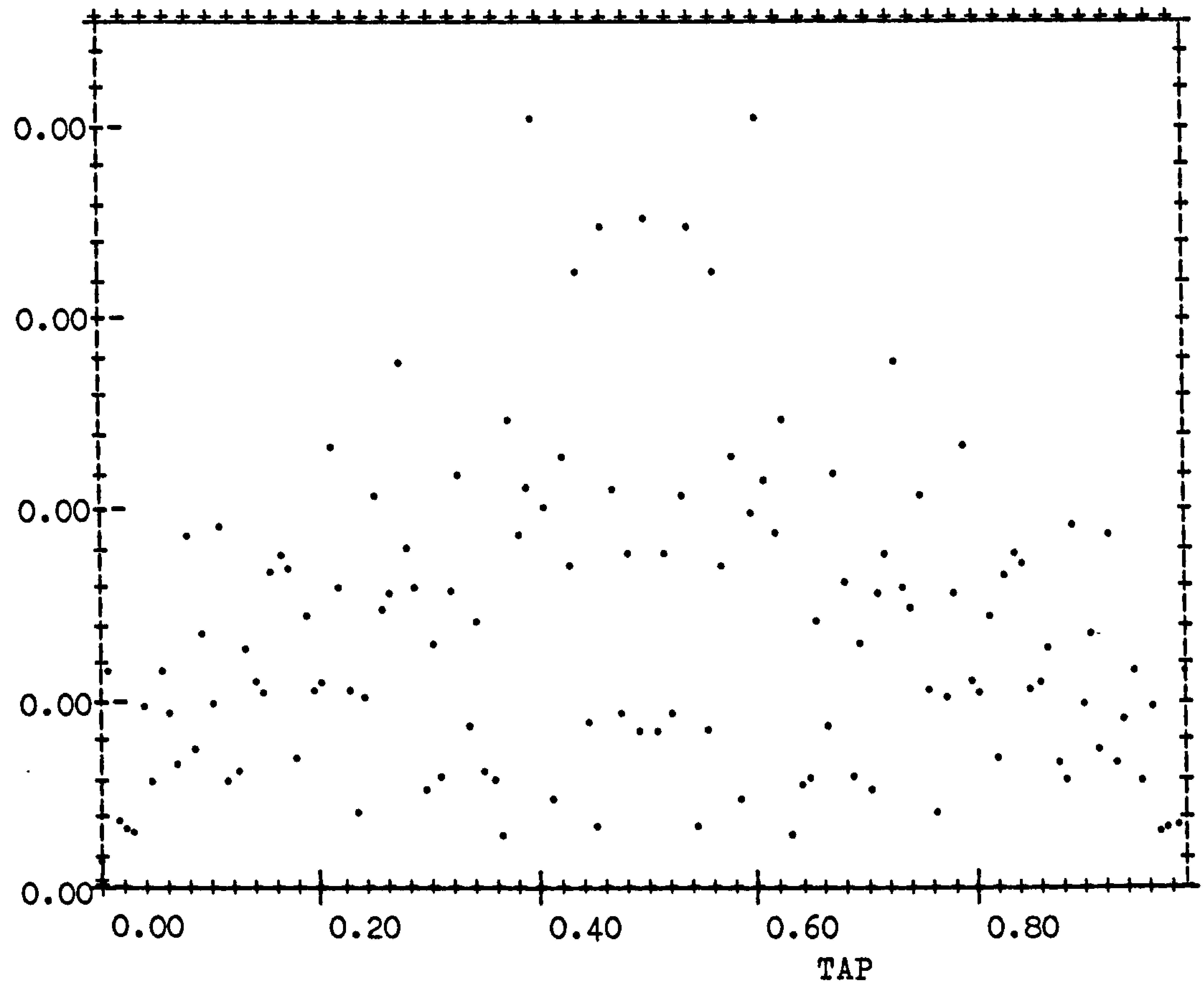


Figure 7.21
Inter beat intervals
Means and S.D.'s

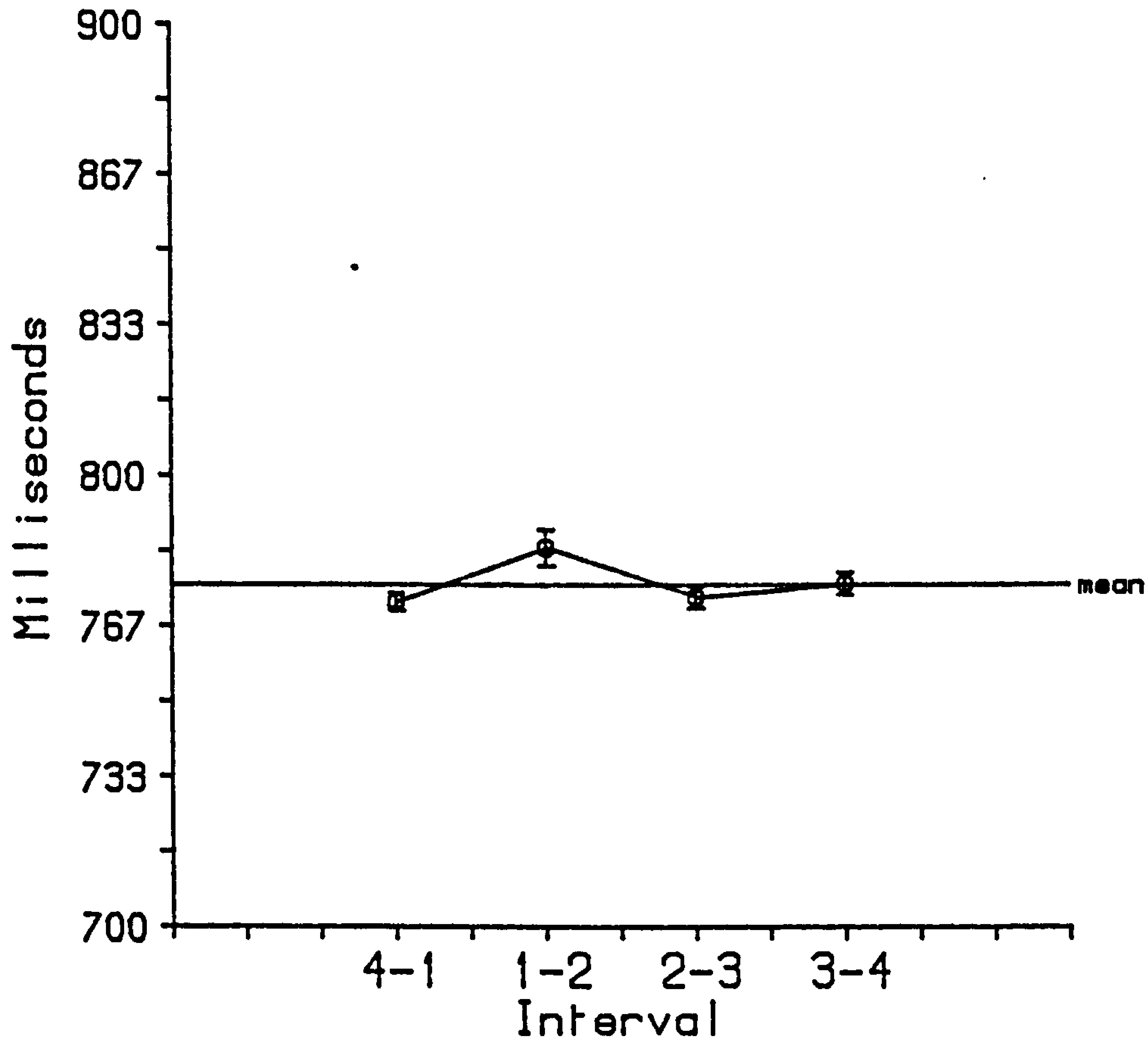


Figure 7.22
Inter beat intervals
Means and S.D.'s

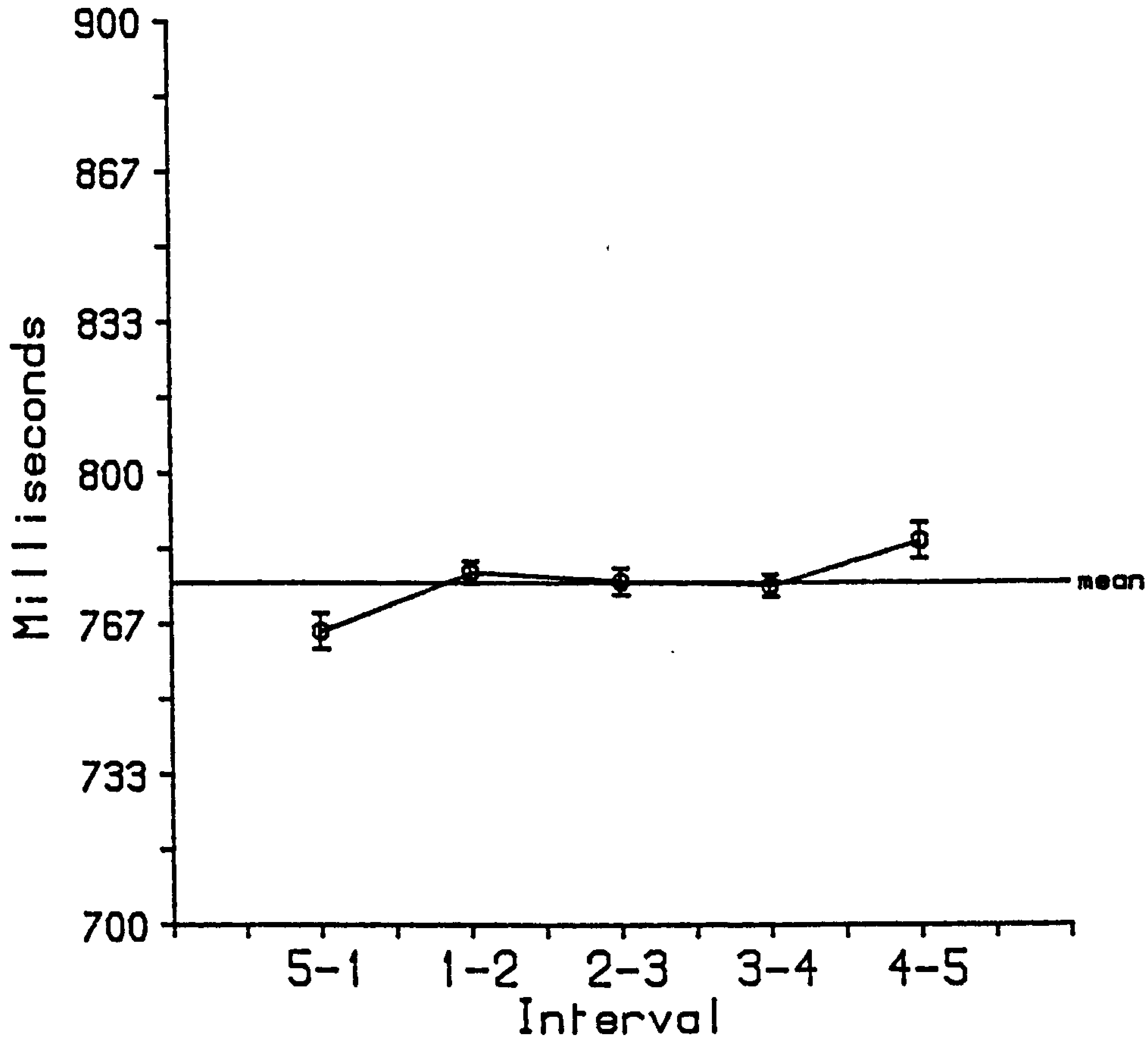


FIGURE 7.23

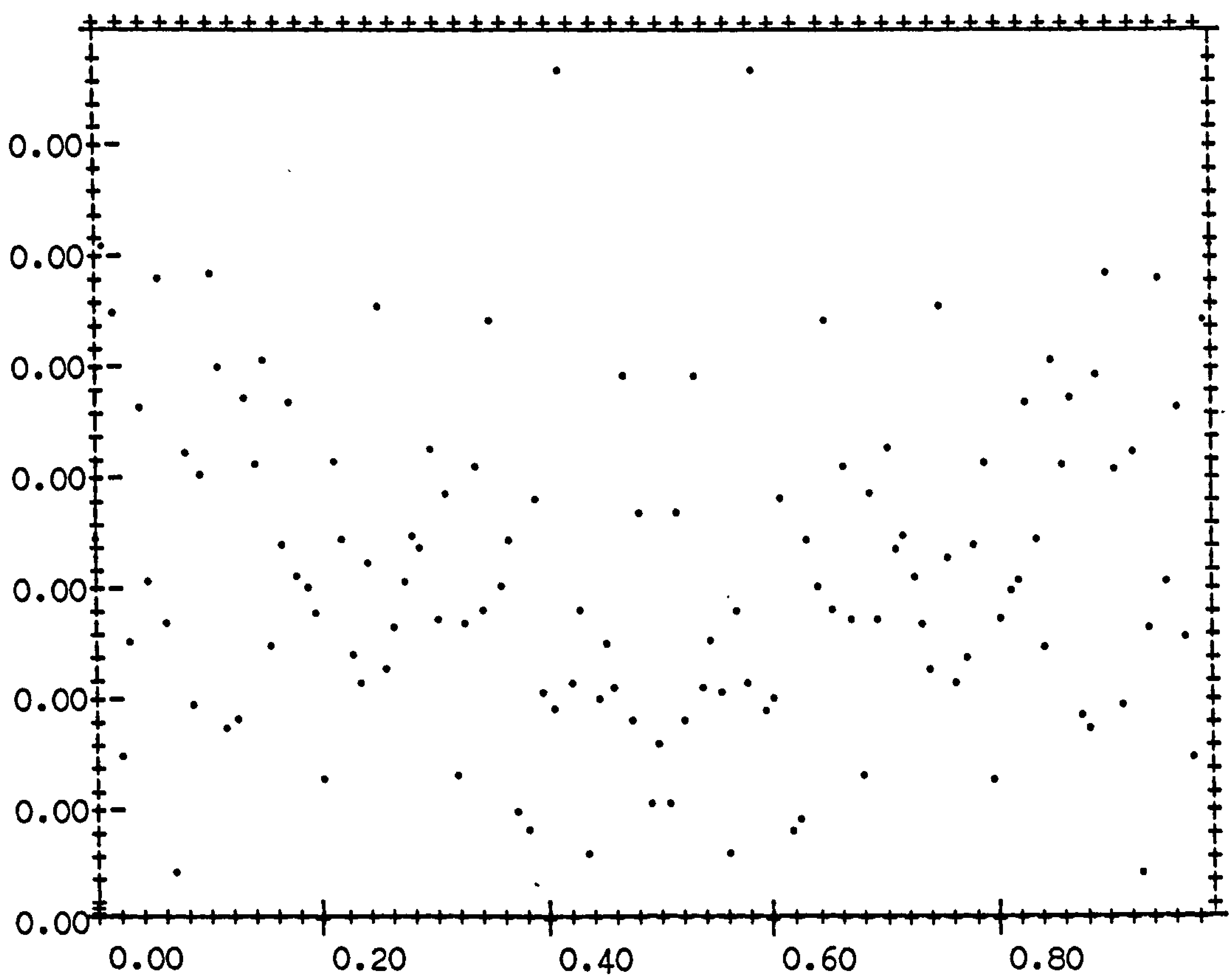


Figure 7.24
Inter beat intervals
Means and S.D.'s

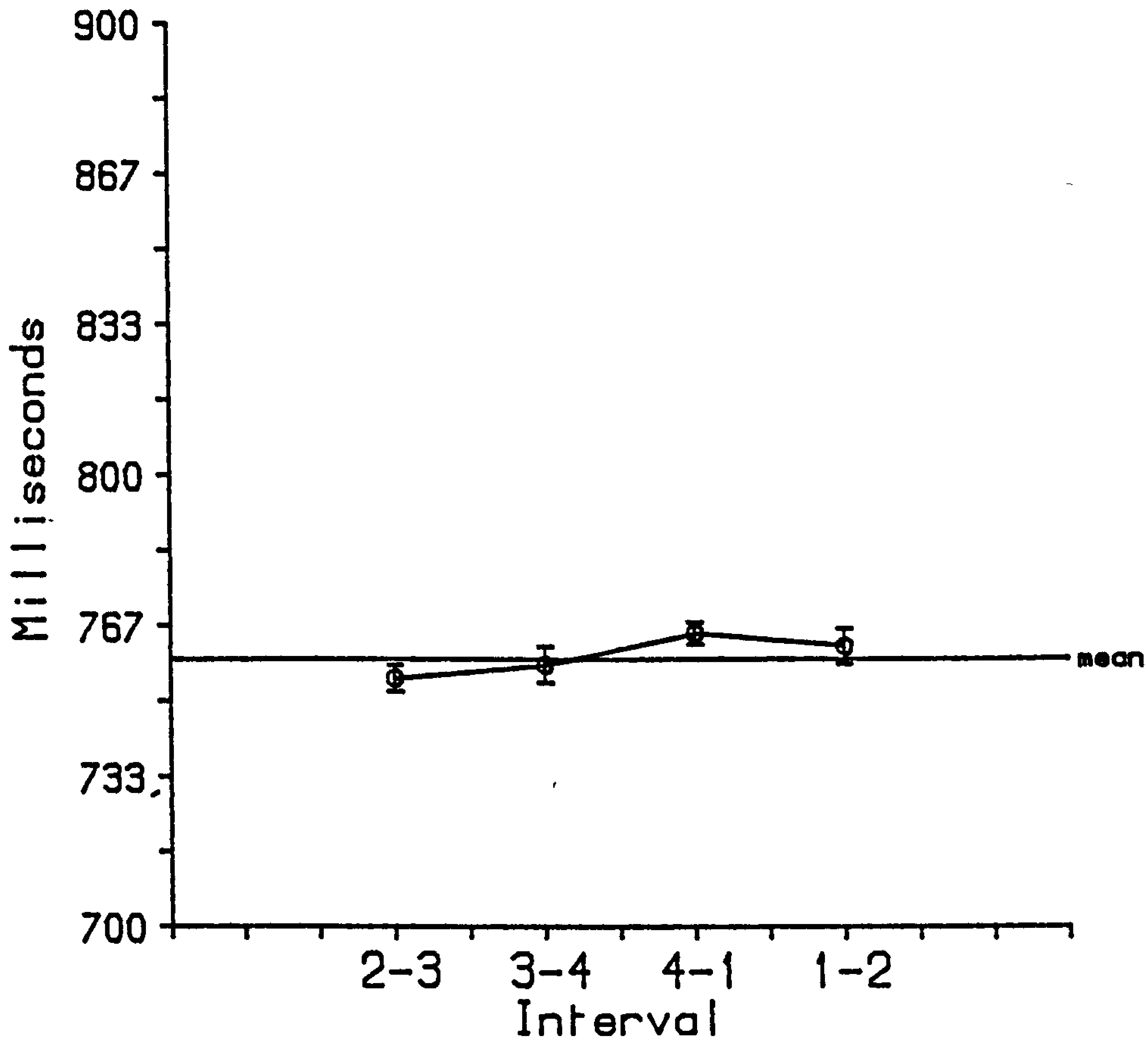


Figure 7.25
Inter beat intervals
Means and S.D.'s

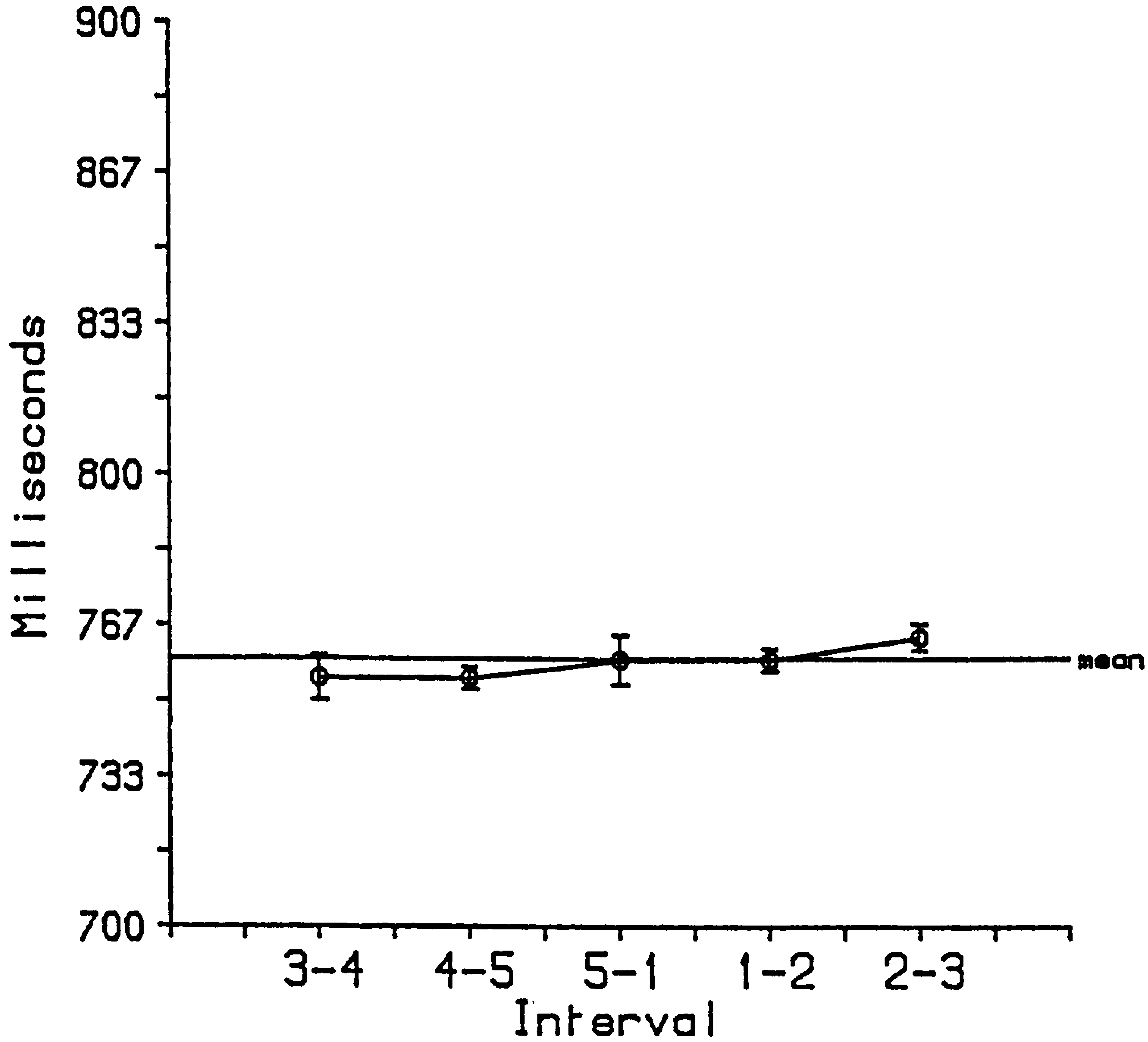


FIGURE 7.26.VARIATION ABOUT MEAN

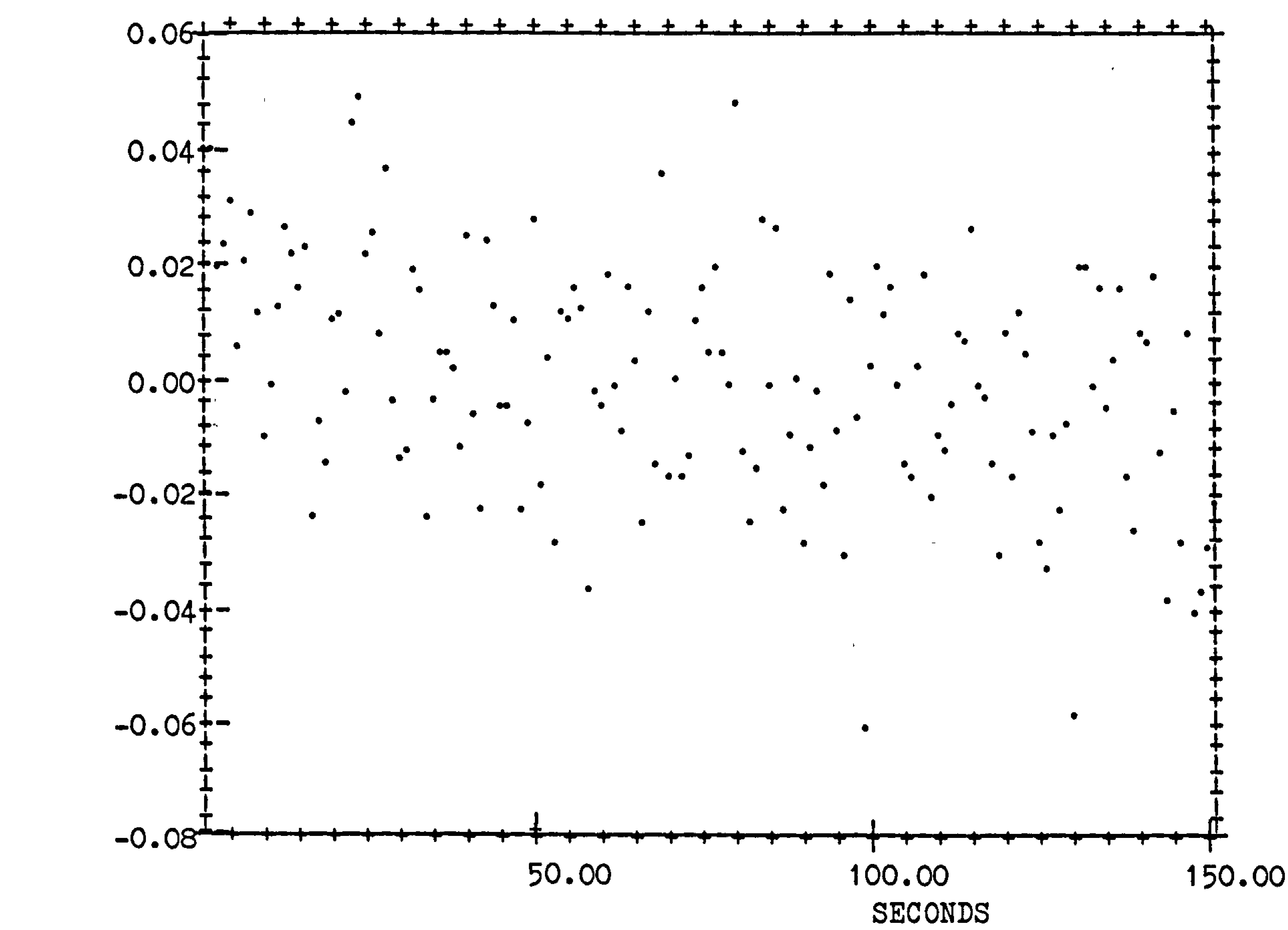


FIGURE 7.27

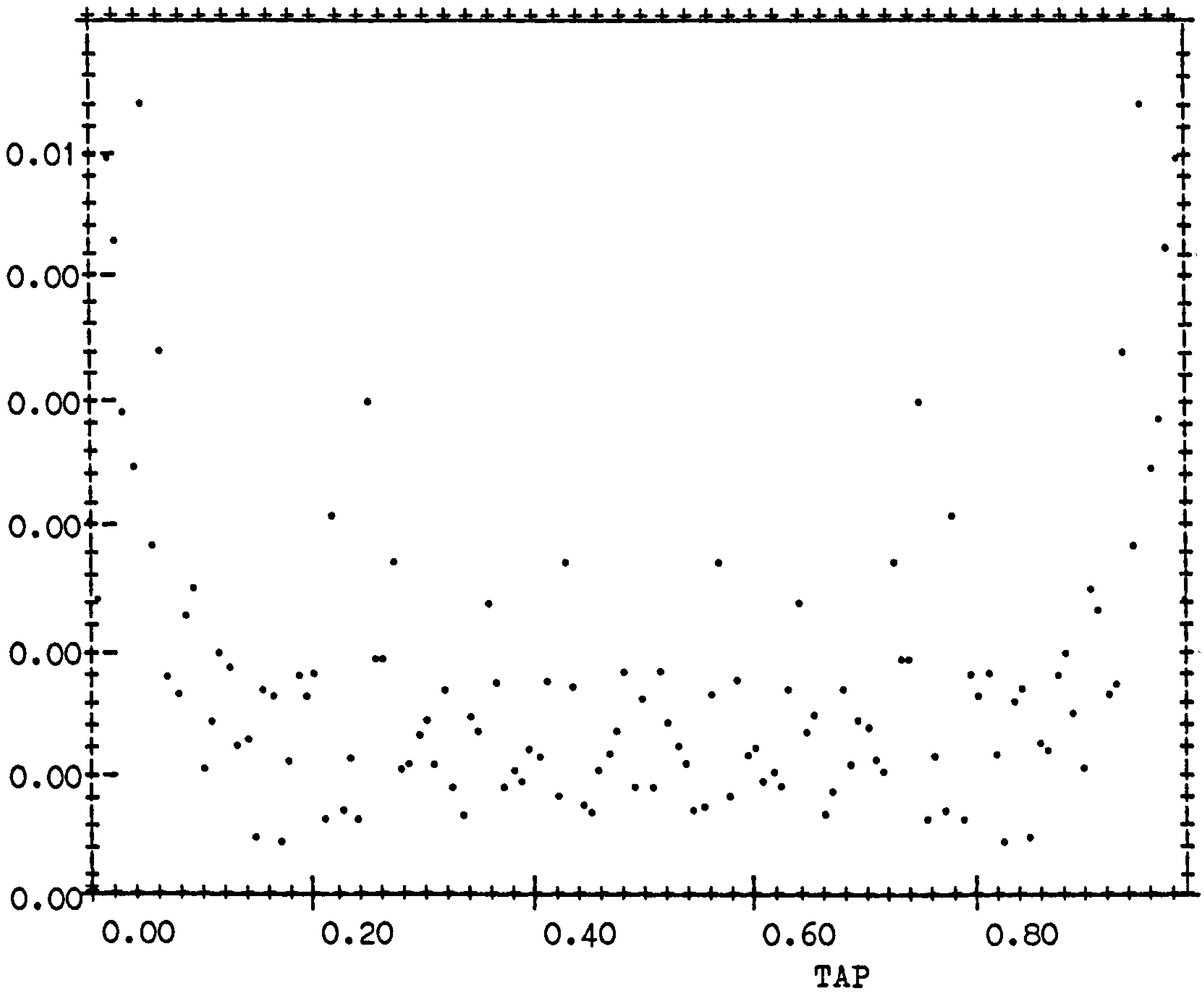


FIGURE 7.28.VARIATION ABOUT MEAN

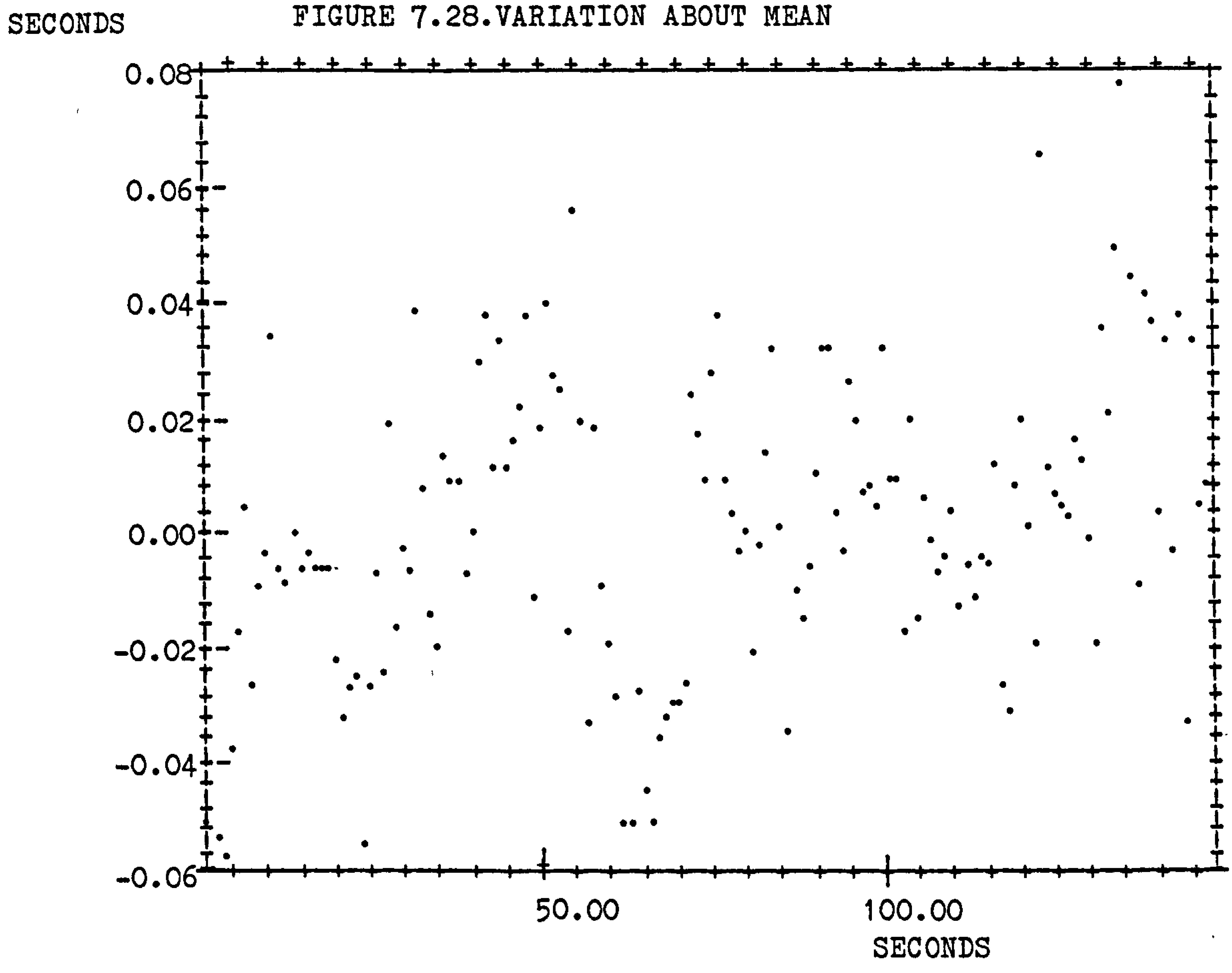


Figure 7.29
Inter beat intervals
Means and S.D.'s

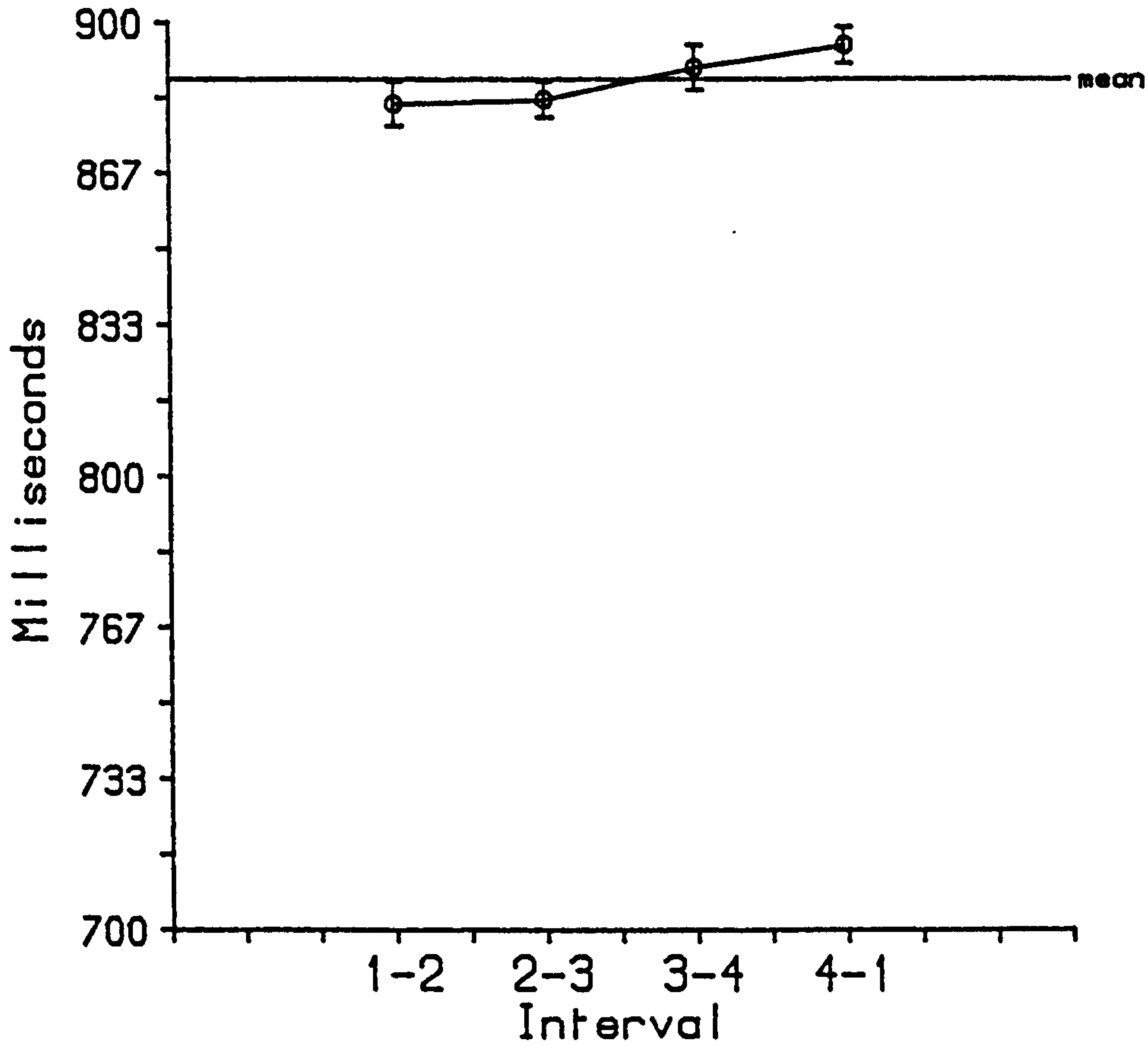


FIGURE 7.30

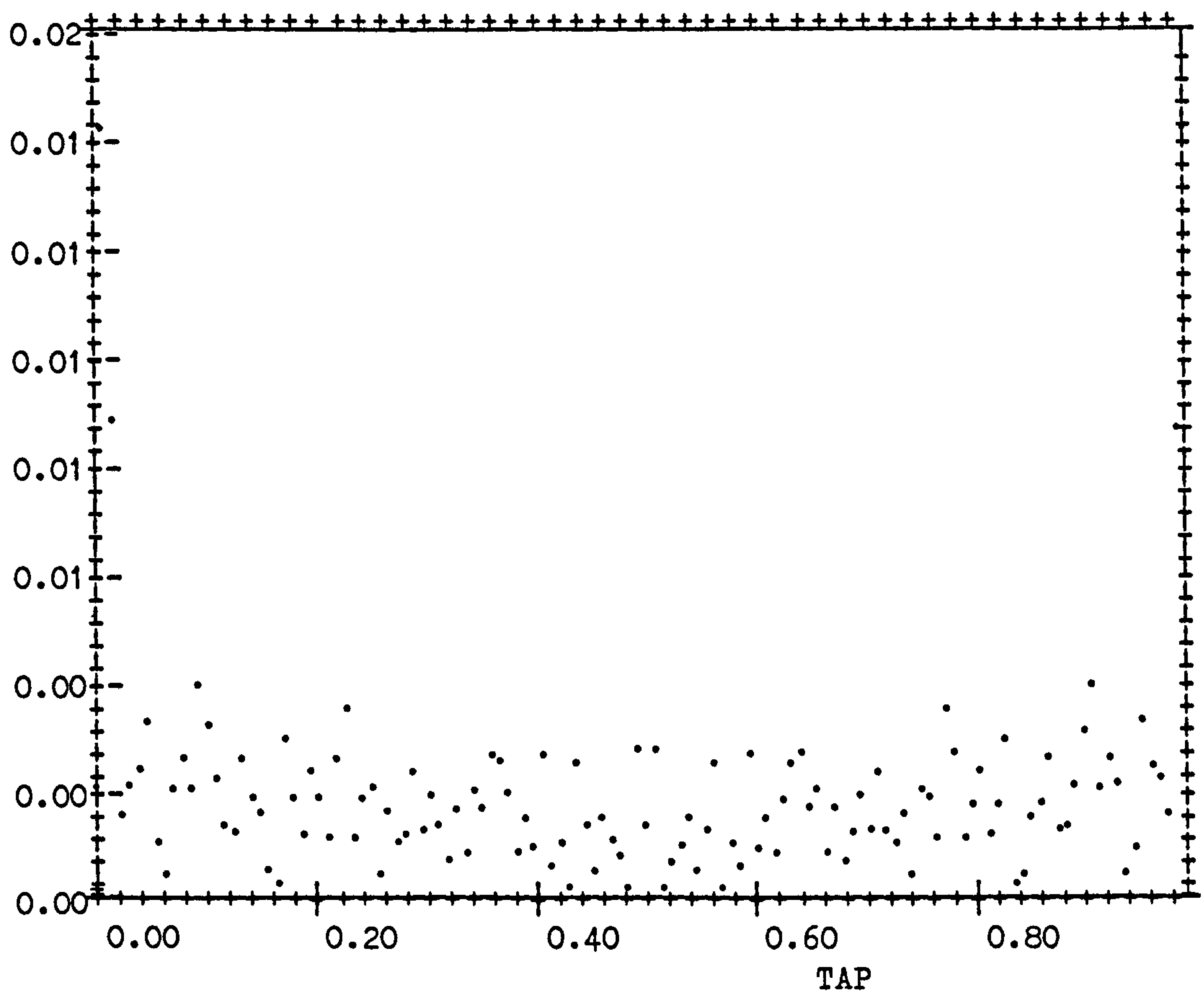


FIGURE 7.31.VARIATION ABOUT MEAN

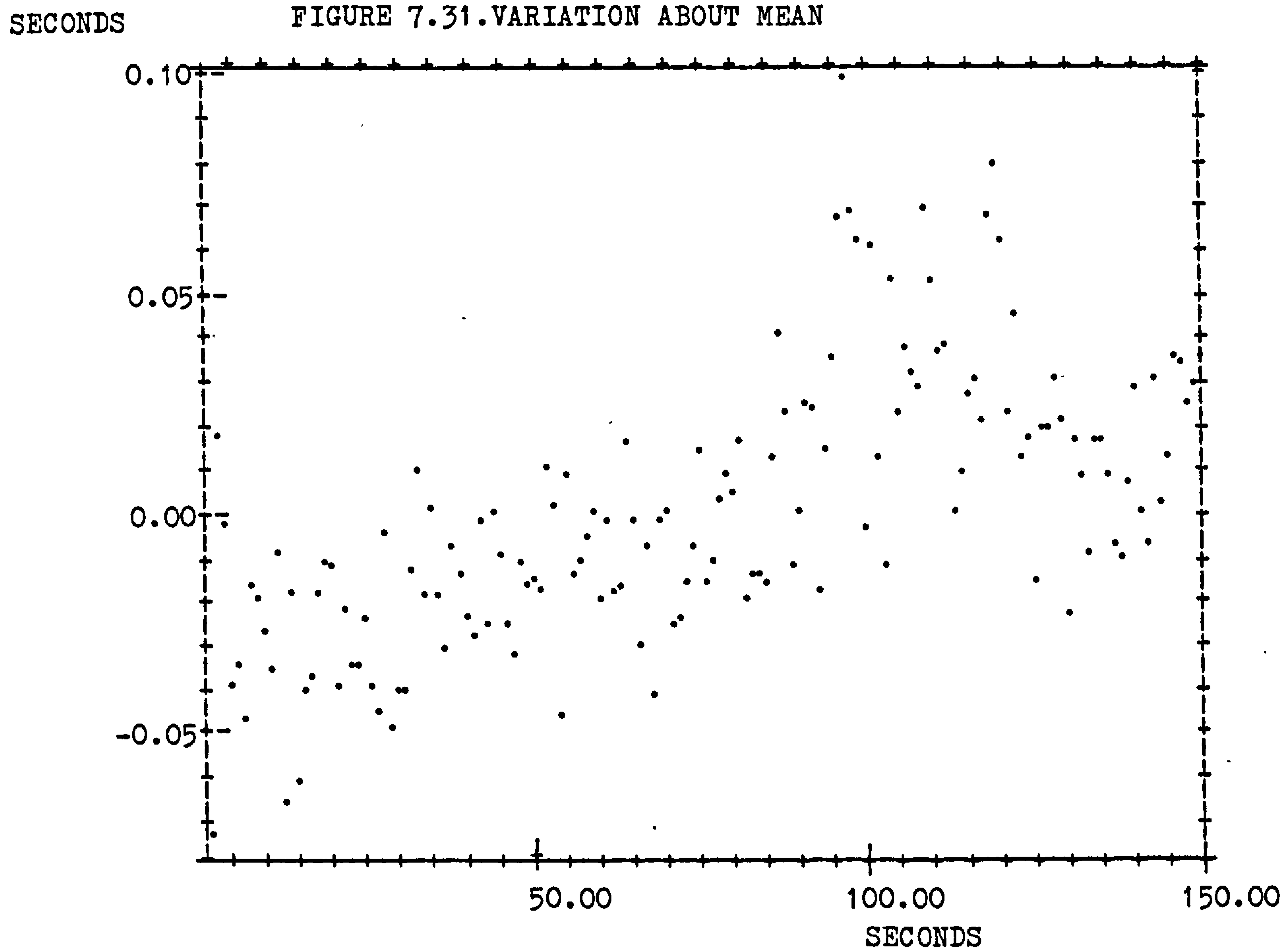


Figure 7.32
Inter beat intervals
Means and S.D.'s

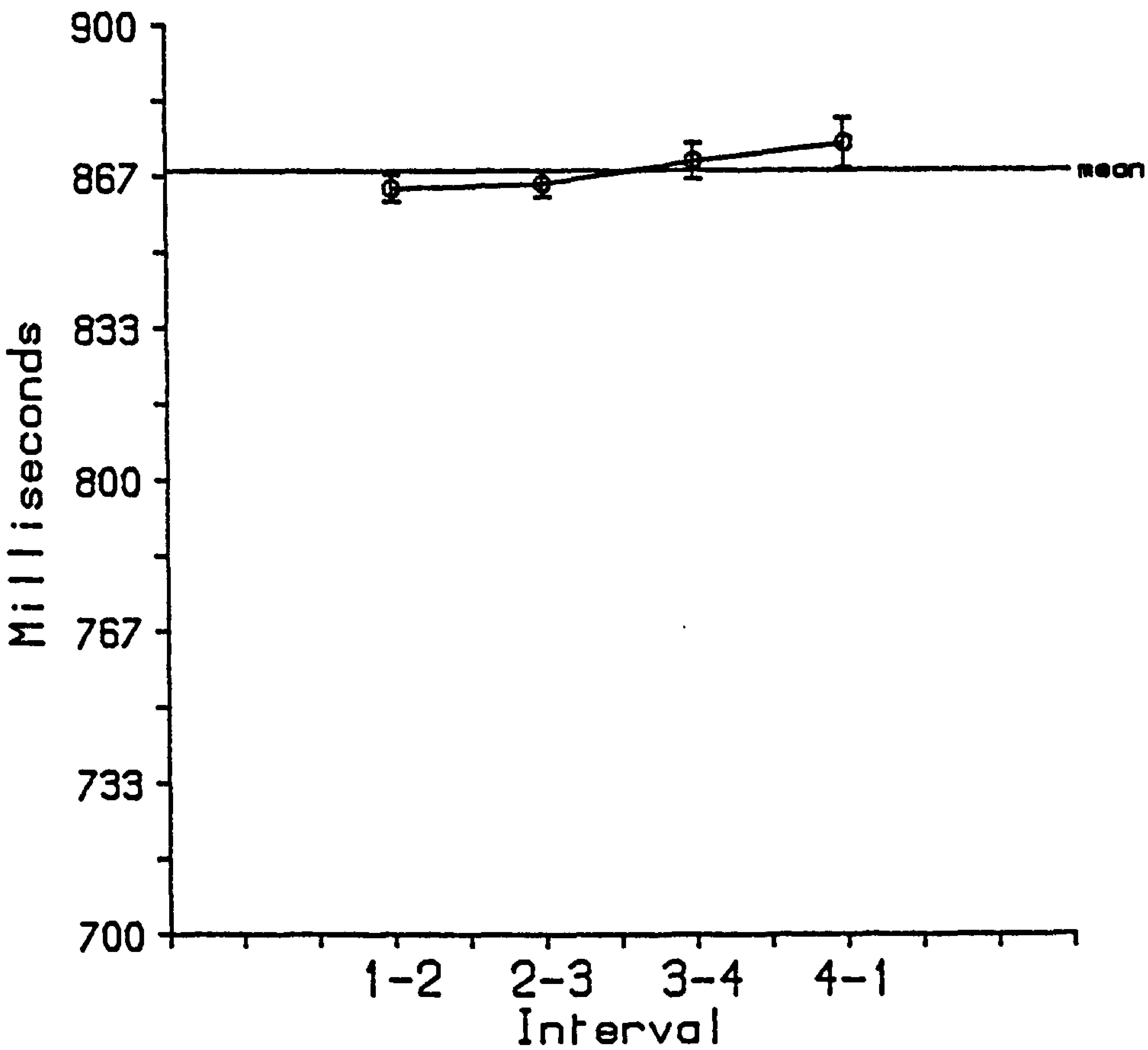


Figure 7.33
Inter beat intervals
Means and S.D.'s

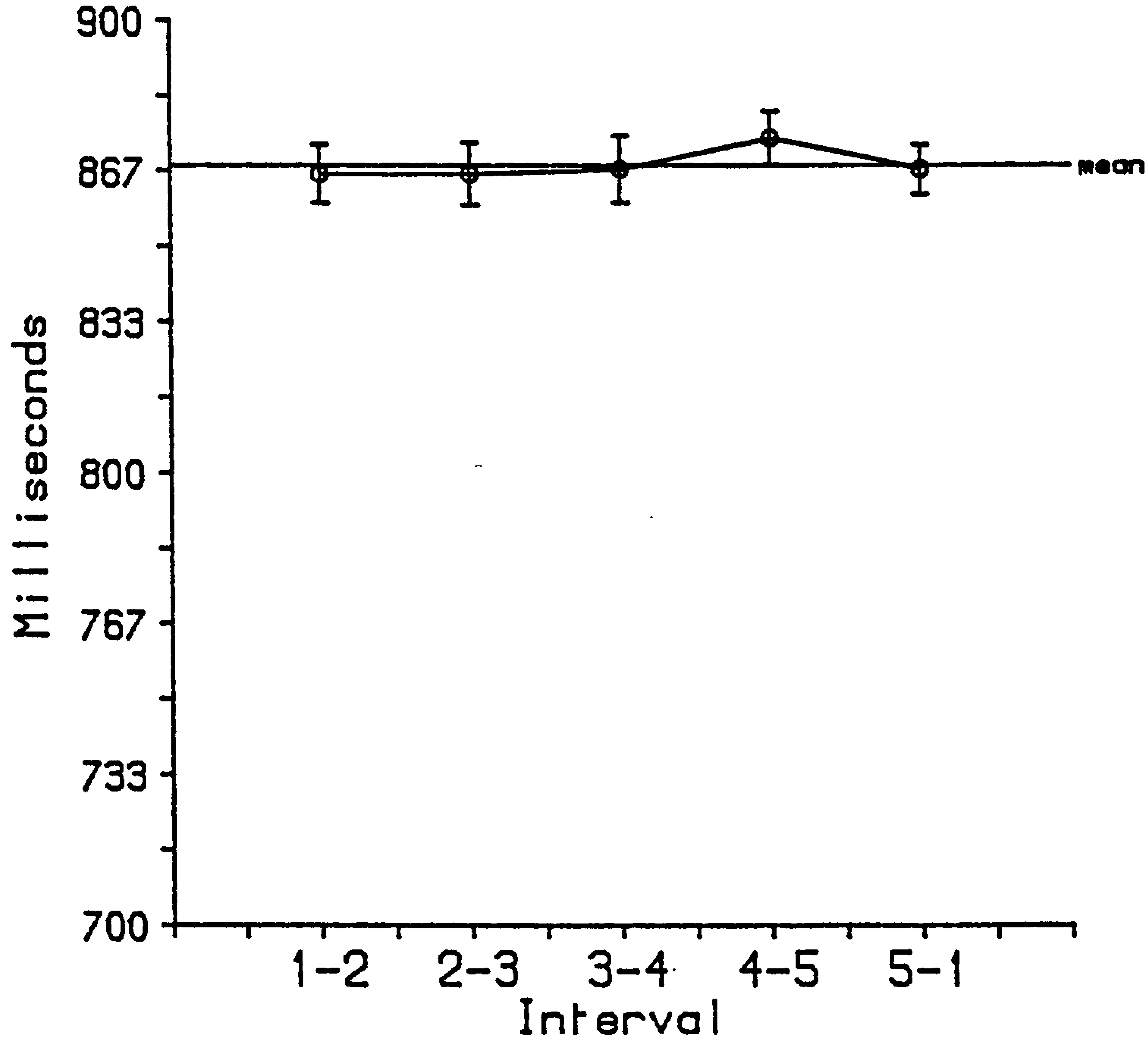


FIGURE 7.34 SUBJECT T.S.

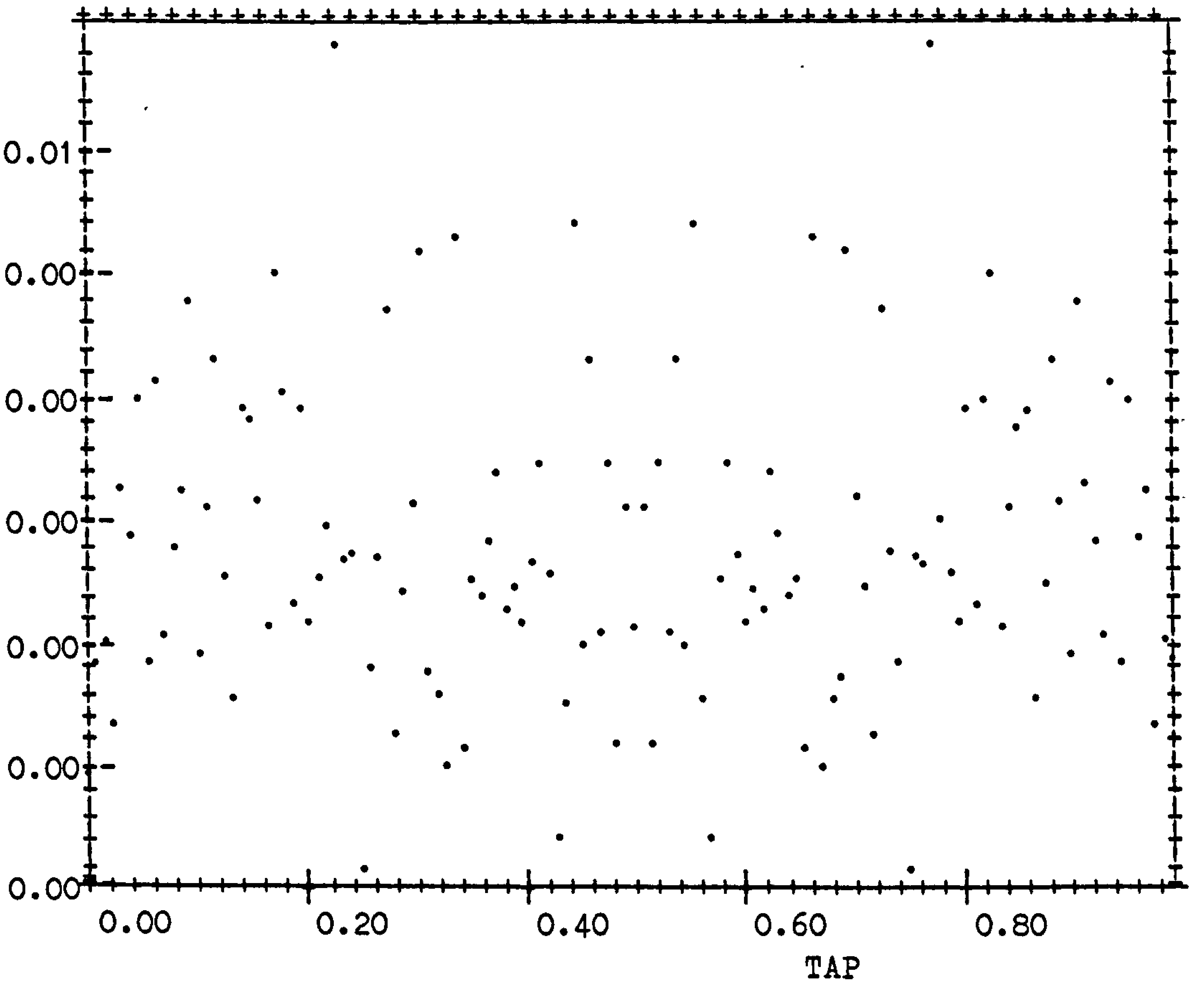


FIGURE 7.35

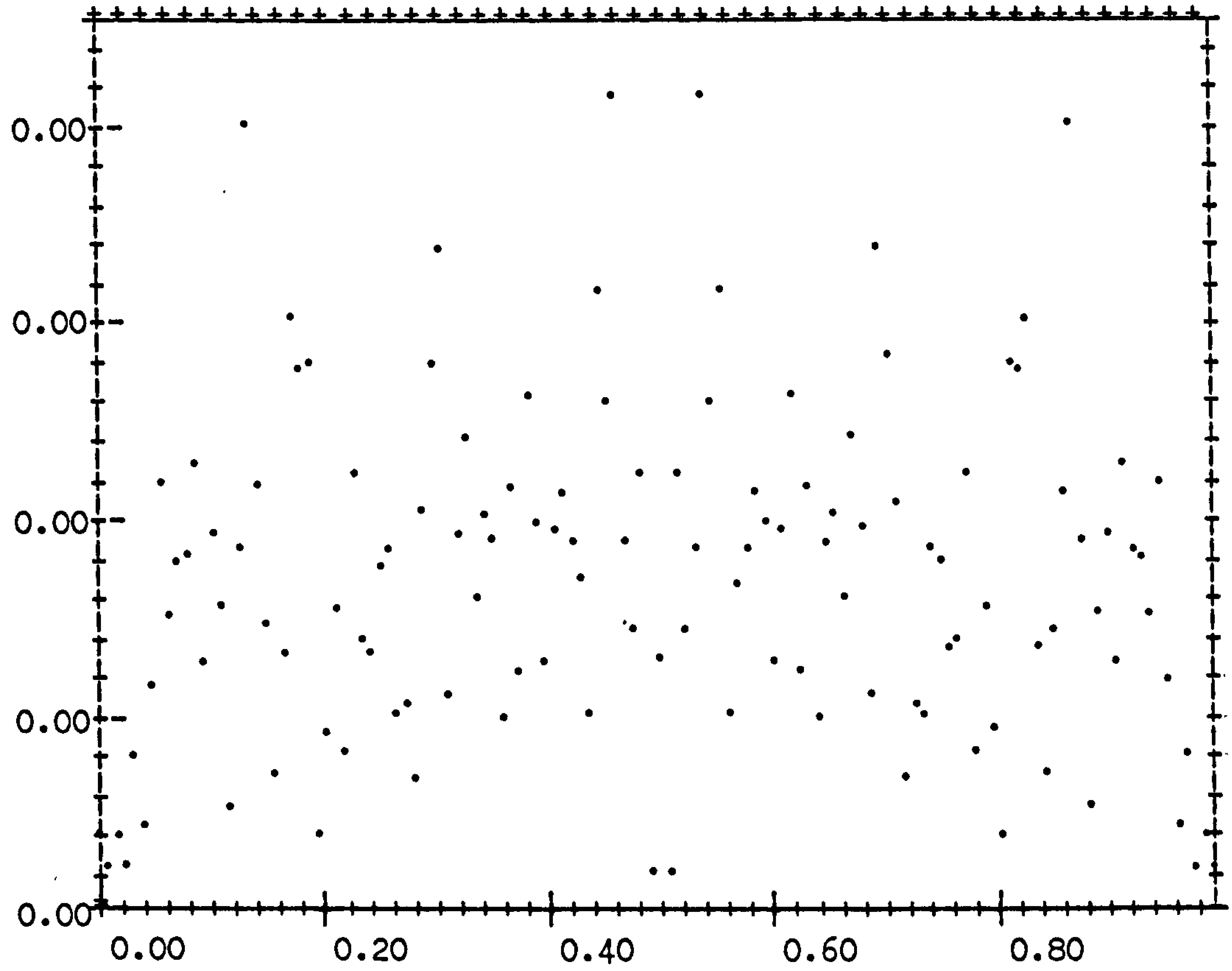


FIGURE 7.36

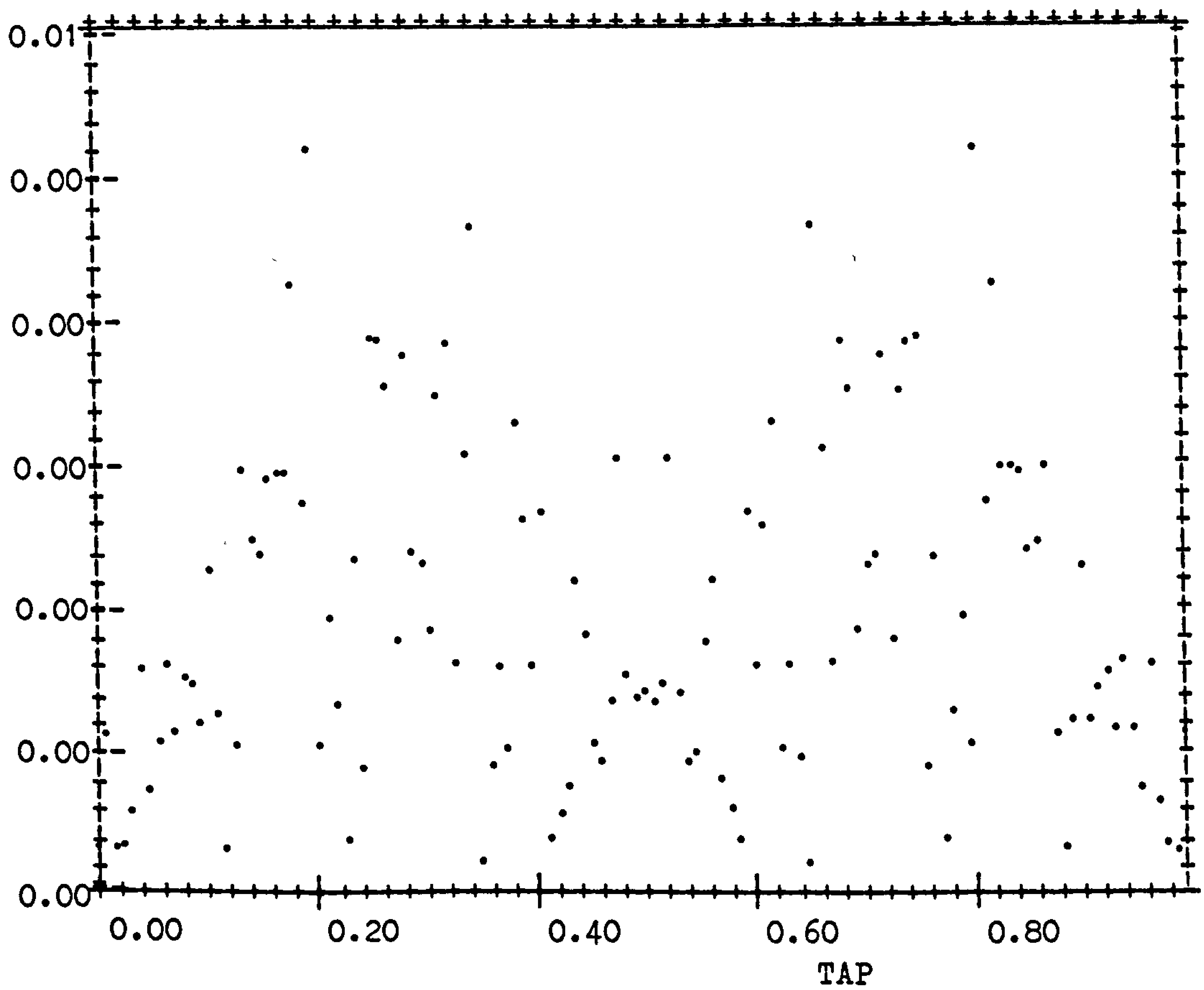
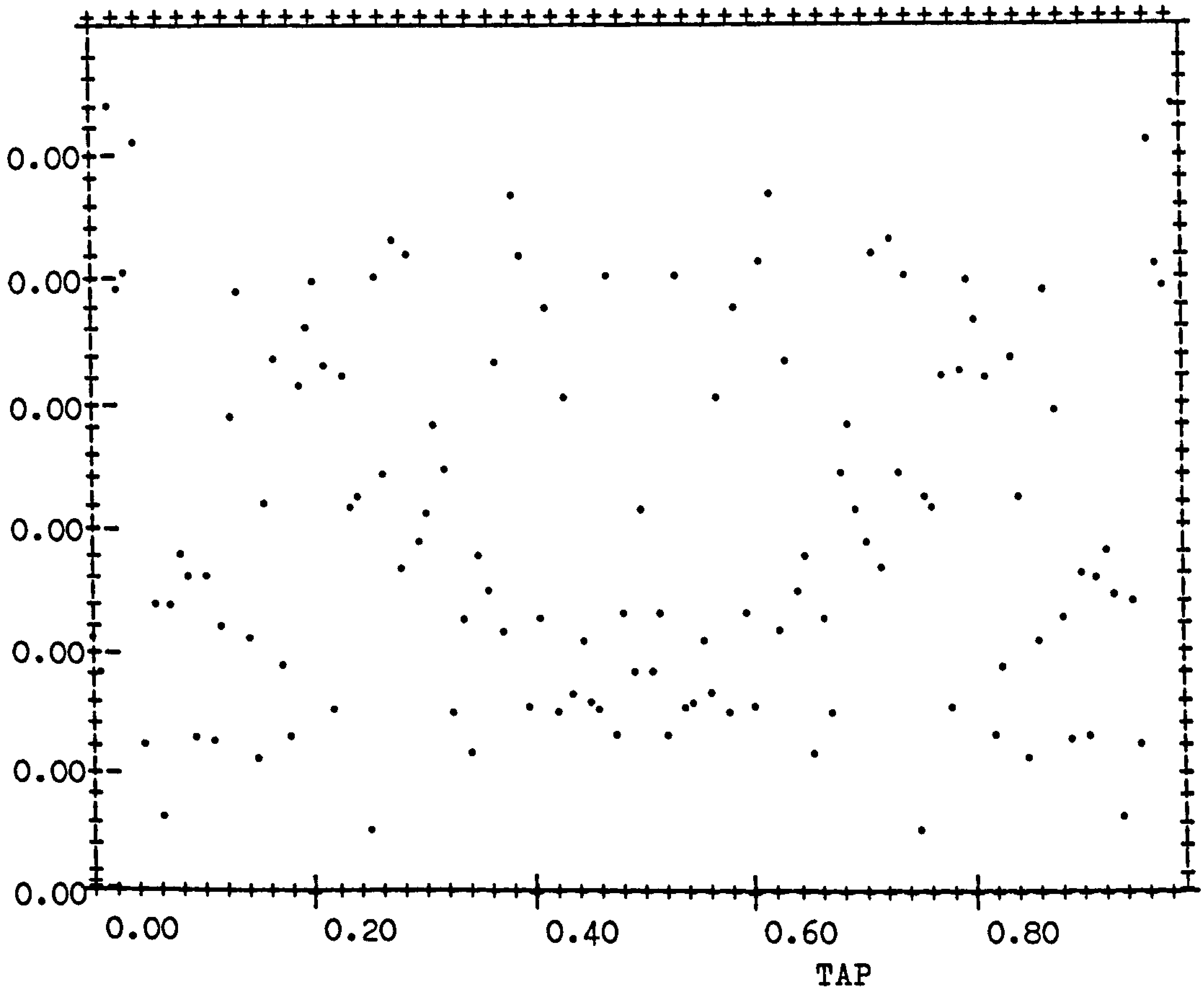


FIGURE 7.37



Discussion

It therefore appears that grouping is endemic. Given an isochronic target series, both subjects almost always grouped their responses. This can be most easily interpreted in terms of the limit cycle oscillator model proposed by Kelso et al (1981), with the addendum that there is a second order of rhythmic organisation which gives rise to the spontaneous grouping of responses.

Clearly, the actual grouping can be controlled and influenced, as this is the most likely way to account for the frequent, but not invariant, coincidence between the number of markers on the disk and the grouping base selected. In spite of the display, A.M. had a clear preference for 4:4 which predominated, tending to prevail over the suggested grouping base, while T.S. selected different bases in each condition.

This last result must be interpreted in the context of the experience of the two subjects. The principal subject, A.M., is a musician who plays a kind of music, rock and jazz, that is mostly in 4:4. This appears to be his naturally preferred choice. The subject reported that as he tapped his way through one hundred and fifty taps tunes would start to run in his mind, which would then start to structure his output. Thus a regular sequence would start to become patterned. T.S. is a classical and folk musician. She had more formal training than A.M., but showed similar preferences for grouping bases.

Chapter Eight

Psychophysical Factors Affecting Timing Accuracy.

Abstract

In this chapter four experiments are discussed. All four concern the factors that affect timing accuracy. The first experiment compares the modalities of available information. Subjects were requested to tap in synchrony with a target series, which could be visual, auditory, or both, or without external cues at all (where the subject had to replicate a tempo from memory). Results indicate that subjects can track an audible series more accurately than they can a series presented visually, and that when both are present and offset, subjects track the audible series in preference. In the second experiment these tap series were analysed to discover whether the variance with which each tap is located in a group is structured or homogeneous. Results indicate that, while the taps themselves may be grouped (see chapter seven), the variance is homogeneous. This section includes a comparison on the Fourier transform procedure with an ANOVA which concludes that when there is low-frequency drift a Fourier transform will elicit genuine grouping when an ANOVA fails to do so. The third experiment makes a comparison between the accuracy of these "active" judgements, when the subject had to operate a switch in attempting to minimise mismatches, and the "passive" judgements reported in chapter six, when the subjects had only to detect and report asynchronies.

Results indicate that the addition of the motor component does entail additional error variance. The last experiment is a small control experiment to ensure that the observed relationship between tempo and accuracy is not an artifact. The phenomenon proves to be real.

Experiment One.

Information Modalities.

Introduction

The concern in this first section is to describe some of the psychophysical limiting factors that parameterise and influence musical performance.

The principal question in this first experiment is whether the information modality in which the target series is presented systematically affects the accuracy with which the subject can follow that series. There are two related questions. Firstly, whether this effect obtains with different subjects. Secondly, how does the accuracy with which a subject can output a tap series without a target series present compare with that achieved with a target series present.

In general, it is clear that responses can be synchronised with anticipated events, and intervals can be matched, with considerable precision. Seashore (1919) and Woodrow (1951) found subject error, in general, to be only a small fraction of the interval to be reproduced. However, there are limits to the interval lengths that can be accurately reproduced. The limits imposed depend on the system deployed.

Firstly, there are sensory rate limits. The upper end of the range for series element detection varies between sensory modalities. Taubman (1950) found that the upper limit to the accurate counting of auditory signals was an inter-signal-rate (ISI) of about 125ms. Bartlett and Bartlett (1959) found that the upper limit with visual signals is slower than that with auditory.

Secondly, there are motor rate limits. Seashore (1938), in another important publication, found that the upper limit of the finger tapping rate was an inter-response-interval (IRI) of approximately 117ms. Practice could increase this rate to an IRI of about 107ms. Dresslar (1892) found that his subjects could achieve IRI's of 98ms. Craik (1947) found that the finger could be moved at a faster rate by electrical stimulation, thus the upper frequency limit must be set by neural control.

The upper end of the range for responding obviously also varies by the motor unit employed, and by the characteristic rate of tremor associated with that unit. This has been shown by Travis (1929) and Lansing (1957), amongst others, who found that response tends to occur in phase with tremor. For finger tapping the fastest possible rate appears to be around 10 cycles per second (cps). The finger tremor typically exhibits a frequency range from 5 to 500 cps (Hauty, 1954), with the component of the greatest amplitude occuring in the range 5 to 12 cps. The maximum response rate may therefore be influenced by the tremor frequency. This does not, of course, mean that 10 cps is the maximum rate of musical note production. Lashley (1951) notes that some musicians can play at 16 notes per second. Certainly, bluegrass banjo players can pick at 16 notes per second, which is equivalent to an IBI of only 62.5ms. This, however, is achieved with a regular cycle of coordinated activity involving three or four fingers, thus the response rate for individual fingers is within the range 187.5ms to 250ms.

At the other end of the range, when a subject is asked to replicate very long intervals, the limiting factor may depend on the accuracy of the representation in memory.

In order to understand the effects of limiting factors in performance, it is necessary therefore to disentangle the contributions and interactions of delays and variances associated with different sensory modalities and with higher level processing and anticipation of external events.

Chase et al (1961) investigated the effect of decreasing feedback on regular and grouped tapping, in one modality at a time- either visual, auditory, or tactile. He found that as the intensity of auditory or tactile feedback decreased, the taps became slower and their intensity increased. His general conclusion, however, was that no one type of feedback seems to provide more sensitive information than any other. This finding is questionable, as the experimental design does not allow single comparisons to be made. It was always possible to compensate for the loss of one modality by continuing to monitor the others.

The first attempt to investigate modal differences in serial tracking appears to be that of Dunlap (1910). He reported that the error indices varied with the intervals between stimuli, that is, that accuracy varies with tempo, but was not precise about the limits of the range of responses.

Bartlett and Bartlett (1959), in an important paper on the synchronisation of motor response and sensory event, started to disentangle the components of the observed variability. Antecedent work by Bartlett and MacLeod (1954) had demonstrated that different sensory modalities are associated with different durations and variabilities of times of reactions to signals. However, in this earlier work, the subjects were given only single signals. This does not permit true anticipation, thus these results are still compounded with possible variations in sensory processing.

In the later work, therefore, as much information as possible was made available to subjects. A similar approach was adopted in the experiments reported here. This allows subjects to act independently of sensory registration by anticipating. Bartlett and Bartlett achieved this by asking subjects to synchronise with one of a series of events, rather than to one event. They make a point of stating, quite rightly, that data from attempts to synchronise with a single event cannot be extrapolated to the tracking of a series.

Amongst Bartlett and Bartlett's findings was a clear practice effect. It is especially interesting that the improvement was a reduction in the number of over-anticipations. Exactly the same phenomenon was reported by the musicians who participated in the studies reported in chapters two to four, that novice and over-anxious musicians were more likely to come in too soon than too late. The investigation was also concerned with tempo, the difference between aural and visual target series presentation, and the difference between different modes of motor response. Six tempi were employed, with ISI's of 125ms, 250ms, 500ms, 1000ms, 2000ms, and 4000ms respectively.

No difference was found for modes of motor response (foot tap as opposed to finger tap). This indicates that the foot tap switch procedure described in chapter three would have caused no loss of accuracy.

The finding for tempo was that at the fastest rates responses were quite random. As the tempo slowed, performance improved until an asymptotic level was reached. Relative error only fell below 10% as the tempo slowed below the 250ms level. Due to the unfortunate lack of data between the 250ms and the 500ms points, it is impossible to say where exactly the tempo became "playable", but it is certainly possible that it fell around the 340ms mark that the conductor G.T. selected as the fastest tempo that would permit individual beats (see chapters two to four). Newell et al (1980) found 300ms to be the critical divide. The timing error function was significantly different above and below this value. They suggest that the use of feedback becomes impossible at the faster rate.

Bartlett and Bartlett found that the relative error remained at the asymptote until the very slow tempi of 3000ms. However, a recalculation of the data revealed that the absolute error started to increase towards 1000ms, and increased rapidly between 1000ms and 2000ms. With musicians, of course, it is the absolute error that is important, as a sufficiently large error will be detected whether the tempo be slow or fast. This finding is, therefore, in agreement with the slow end of the range selected by G.T., who would start to subdivide the beat as the tempo slowed below an IBI of 1200ms.

The cross-comparison reveals that performance was superior with auditory signals to that with visual signals, at every tempo. With simultaneous auditory and visual presentation, performance was no better than with auditory information alone. Bartlett and Bartlett placed the upper limit for visual responding to between 333ms and 250ms, as compared to the figure of 125ms for auditory monitoring mentioned earlier.

Bartlett and Bartlett came to the following conclusions. Firstly, the variability of attempts to synchronise with an element in a series is greater than the variability of simple reactions to single stimuli. This they attribute to "variability in the anticipatory mechanism". Secondly, auditory information permits greater accuracy than visual. Thirdly, that there are no significant differences in the variabilities of the motor response mechanisms tested.

Methods

There were three conditions, in which information was presented in different modalities. In two of the conditions, subjects were asked to follow a single series. This would be either of visual events or of auditory events. In the visual series condition subjects were requested to watch a rotating disk and tap a switch when markers on the disk coincided with a fixed marker at the side of the disk. In the auditory series condition subjects closed their eyes and tapped a switch in time with a series of clicks.

In the third condition subjects were asked to tap with both a visual and an auditory series present. As the purpose of this experiment was to contrast the sources of information, the visual and auditory series were not synchronised exactly before the start of recording, as was done in other experiments. Instead, a session would start with the two series entrained, but with a large offset equal to approximately one-third of the IBI. The experimenter would then adjust the offset until the subjects reported that the series were synchronised. In order to obtain the clearest possible demarcation between categories, it was desireable that the offset be left as large as possible, but it was also necessary that the subject be unaware that this was the object of the exercise and that any offset remained. This was because the purpose of this procedure was to discover whether a preference for either modality existed without influencing the subject's choice. This procedure accounts for the large inter-subject differences in the offsets that were tolerated, as will be observed.

Finally, in the fourth condition, subjects were requested to tap alone with no target series present, and to replicate the tempo of the previous trials with targets. A delay of approximately ten minutes was interposed between the last target series recording and this non-target series recording. Table one summarises the cross-matching of variables.

Table one

Cross-matching of experimental conditions.

Tempo	Target Series			
	Visual	Auditory	Both	Isolation
Larghetto	Y	Y	Y	Y
Moderato	Y	Y	Y	Y
Prestissimo	Y	Y	Y	Y

Results.

There are a number of clear results, which will be considered under seven headings.

Firstly, tables two and three show that the S.D.'s are invariably smaller when an auditory series is present than when a visual series is present. This means that the auditory series may be tracked with less error than the visual series.

Secondly, the S.D.'s obtained when both an auditory and a visual series are present are generally closer to the values obtained when an auditory series alone is present than when a visual series alone is present. There are two exceptions to this rule, but only one is marked (subject T.S., at larghetto). The implication here is that where both visual and auditory information is present, the auditory series is tracked preferentially.

Table two

Differentiation of successive points to give I.B.I.'s.

Subject A.M.

Tempo	Modality	Target ITI	Subject Mean ITI	Subject SD
Prestissimo				
	Visual	345.2	344.7	15.6
	Auditory	341.2	341.1	12.9
	Both	340.6	340.3	10.3
	No target		345.2	10.0
Moderato				
	Visual	806.1	805.8	29.5
	Auditory	812.8	812.4	20.4
	Both	783.8	784.1	20.0
	No target		887.8	26.6
Larghetto				
	Visual	1199.0	1198.1	37.3
	Auditory	1187.4	1187.4	26.7
	Both	1199.8	1199.4	30.3
	No target		1224.8	53.7

Table three

Differentiation of successive points to give I.B.I.'s.

Subject T.S.

Tempo	Modality	Target ITI	Subject Mean ITI	Subject SD
Prestissimo				
	Visual	334.7	338.6	14.2
	Auditory	333.9	334.1	13.6
	Both	334.7	335.1	14.1
	No target		331.0	11.4
Moderato				
	Visual	784.4	784.2	34.2
	Auditory	786.5	786.7	21.4
	Both	786.4	786.8	25.6
	No target		814.2	19.0
Larghetto				
	Visual	1221.4	1220.2	44.7
	Auditory	1211.3	1209.7	41.9
	Both	1224.7	1223.4	53.2
	No target		1345.2	67.9

Thirdly, tables four and five show that when the visual and auditory series are offset, the subjects (with only one exception) tap more closely to the auditory series than to the visual series.

This is in accord with the first two results.

Table four

Target Series - Tap Series

Subject A.M.

Tempo	Modality	Mean Difference	N
Prestissimo			
	Visual	77.2	151
	Auditory	5.5	135
	Both(visual)	0.7	151
	Both(auditory)	31.3	151
Target series offset		30.6	
Moderato			
	Visual	8.7	149
	Auditory	0.6	150
	Both(visual)	90.2	149
	Both(auditory)	-3.6	149
Target series offset		-93.7	
Larghetto			
	Visual	63.9	150
	Auditory	36.3	151
	Both(visual)	123.9	150
	Both(auditory)	19.6	150
Target series offset		-104.2	

Table five

Target Series - Tap Series

Subject T.S.

Tempo	Modality	Mean Difference	N
Prestissimo			
	Visual	126.8	152
	Auditory	6.9	153
	Both(visual)	6.1	152
	Both(auditory)	3.0	152
Target series offset		-3.0	
Moderato			
	Visual	65.6	150
	Auditory	13.8	151
	Both(visual)	21.6	150
	Both(auditory)	17.1	150
Target series offset		-4.6	
Larghetto			
	Visual	16.8	150
	Auditory	21.8	150
	Both(visual)	7.9	150
	Both(auditory)	3.2	150
Target series offset		-4.8	

Fourthly, although subjects correctly match the average target interval, their responses were not always synchronised. Asynchronic responses were only observed when the information modality was visual. Both subjects operated at large offsets at prestissimo, A.M. did so additionally at larghetto and T.S. at moderato. This, in conjunction with the fact that it was possible to impose offsets at all, is in accord with the finding in chapter six that the subject's target does not necessarily correspond exactly with the set target. It also means that the process of accurate derivation of a target IBI, the incorporation of that rate in to a regular output action, and the consequent entrainment of responses to the target frequency, is not the same process as synchronisation with the actual target events.

Fifthly, when asked to replicate a tempo after some delay and masking, both subjects can do so accurately. There is a slight tendency on the part of both subjects to tap more slowly without a target, although there is one instance of a faster tap, but the average increase in IBI is only 4.5% while the S.D. of that mean is 5.1%. The difference is not significant.

Sixthly, in the no target condition, the S.D.'s for both subjects were substantially higher than in the target condition, but only at the slow tempo. At moderato and prestissimo the S.D.'s were similar or smaller than those obtained in the target conditions. This means that it must be possible to operate a regular action pattern in the no target condition with less error than when there is a necessity to incorporate feedback, but that this occurs only within certain bounds. The longer the interval, the harder it is to replicate precisely, although the mean IBI is reproduced, even at larghetto, with tolerable accuracy (within 2.5% in the case of A.M.).

Seventhly, there was a large inter-subject difference in the toleration of offsets. The largest offset tolerated by T.S. was -4.8ms, whereas A.M. allowed -104.2ms.

Discussion.

These results confirm Bartlett and Bartlett's findings on a number of points. Firstly, auditory tracking may be done with greater precision than visual tracking. This result was also obtained by Fraisse (1964), Hirsch et al (1956), and Goldstone and Goldfarb (1964). Secondly, where both visual and auditory information is present, performance is generally closer to that obtained with auditory alone to that obtained with visual alone. The covert use of offsets between the visual and auditory series allows the additional observation to be made that when there is a discrepancy between the target series, the auditory is tracked in preference.

Thus the visual system seems to be inherently less sensitive than the auditory for this kind of tracking task. This may explain the finding described in chapter two, that musicians prefer to synchronise with a musician (where the information is auditory) rather than with a conductor (where the information is visual).

The finding that matching of IBI's, i.e. entrainment with a target series, and precise point matching, i.e. synchronisation with a target series, are not identical processes is also a considerable development of Bartlett and Bartlett's idea that synchronisation with a single event is not the same phenomenon as series tracking. The conclusion here is that IBI tracking itself is not the same as synchronising with a series. Logically, therefore, entrainment and synchronisation must be separate processes.

This might explain the finding, described in chapter four, that there is an essential arbitrariness in the synchronisation of a musician's actions with phases of the conductor's baton movement. This arbitrariness, and the way in which understanding as to which phase of the conductor's baton action is to be targetted is arrived at in rehearsal may reflect the operation of the synchronisation rather than the entrainment process.

The discrete nature of the two processes may also be seen in the finding of chapter six, that subjects could match a given offset between visual and auditory events very precisely. This emphasises the arbitrariness of synchronisation. Finally, the finding that a tempo can be quite accurately replicated after some delay can only reflect the internalisation of the entrainment function, as there is then nothing with which the subjects could synchronise.

These findings, all suggesting the separateness of the two functions, clearly must affect the way in which we understand the accuracy of performance in the musical situation.

The underlying reason for the discrete nature of these two functions may lie in the operating characteristics of the muscle synergies deployed in the task. A muscle synergy, if it manifests the properties of a limit cycle oscillator, may be set to operate at a given frequency within the confines of the range of that particular synergistical organisation. A given frequency may be internalised and actualised in the organisation of the muscles. This would clearly give entrainment, but not synchronisation. Entrainment, then, is a function at the level of the motor program. Synchronisation is what is then achieved, either with a given event or with a set offset to that event, in rehearsal and in response to feedback. Synchronisation, therefore, must be under more conscious control.

The operation of this second stage synchronisation process must introduce a further element of variance, as is demonstrated in the finding that subjects could (with a few exceptions, determined by the effect of the tempo factor) operate a more regular output series when they had no target series with which to synchronise.

Thus while the entrainment process reflects the operation of the muscle synergy, synchronisation must be achieved by controlling the frequency driver which interacts with the synergy to determine output.

Experiment Two.

Part One: The variability of IRI's within a group.

This experiment was concerned with the variability with which IRI's are located in a group. The principal finding of chapter seven was that output taps are grouped. The question here is whether the accuracy with which each tap is located in a group itself varies systematically. The Vorberg and Hambuch model (see chapter seven) would predict that the tap located last in a group should be most variable, as they assume that the group onset time is the controlled variable. Shaffer's model (see chapter seven) would predict that the first tap in a group should be most variable, as temporal targetting implies increased constraint towards the end.

If, however, grouping is a system-emergent property, then there is no a priori reason why any event in a given grouping should be more precisely located than any other, although this obviously applies only to the situation where there is either a mechanically regular target series or no target series. If the target series is itself variable, as is the case when musicians must synchronise with each other, then there will have to be strategies for controlling progressive divergence which entail temporal targetting (see chapter seven).

Part Two: The relative accuracy of "passive" and "active" judgements.

There is another reason for performing this analysis. Experiment three is concerned with the relationship between perception and production, and whether the requirement to produce a tap entails additional variance to that associated with the perception of synchrony. In order to do this, it was necessary to analyse the variance of the S.D.'s in the production condition series in order to determine whether the variance could be pooled for the purposes of the comparison.

A comparison was therefore made between the replicateability of judgements in a "passive" condition, where the subject had to assess a degree of asynchrony, with those made in an "active" condition, where the subject had to produce a series of taps while attempting to minimise the asynchrony between the taps and the target events.

As experiment three follows on from experiment two, the methods sections have been combined.

Methods

Performance in active and passive conditions was compared at the same three levels of tempo, larghetto, moderato, and prestissimo, and within the three modes of target series presentation, visual, auditory, and both visual and auditory.

From the finding reported in chapter six: that visual-auditory asynchrony is in part arbitrarily selected, it follows that the sizes of the offsets cannot be used as the sole criterion of accuracy. Thus it is not possible to compare the absolute sizes of the discrepancy between the tap and the target series event on the one hand, and the perceived visual-auditory asynchrony on the other. However, it is possible to use the S.D.'s of equal numbers of consecutive performances as an index to the accuracy or consistency with which the subject could make or excecute a judgement.

In the "passive" condition, the procedure is straightforward. A S.D. is calculated over five attempts to replicate a selected offset.

In the "active" condition the inter-tap-intervals (ITI's) might vary systematically within a bar while retaining a consistent pattern of variation over five bars. For example, variation within a 4:4 bar might be composed of a long, short, short, short, while this grouping could be regularly repeated over a number of bars. It is the consistency of the patterning on the ITI's that is of interest, rather than the absolute size of the intervals, and it is these

S.D.'s that are used in the comparison.

In the data from the "active" condition the "bars" are actually subsets of consecutive taps from within series of about one hundred and fifty taps. This length was required to answer other questions dealt with in chapter seven. It is not possible to directly compare the S.D. of one hundred and fifty taps with the S.D. of five consecutive judgements, as certain superordinate considerations, such gradual drift with respect to the target series (this is explained below) can only appear with the longer series. Therefore it was necesssary to select sequences of taps from within the production series.

Tap Selection Procedure

The method of selection was as follows:

(1) The tap series was Fourier transformed, and the amplitudes of the transform calculated. The largest contribution that corresponded to an integer multiple frequency was taken to be the grouping base adopted (the rationale for and the explanation of this procedure are given in chapter seven).

(2) The original target and tap series were matched for length and start point.

(3) The target series was then subtracted from the tap series. The resultant was the differences series.

(4) The mean and S.D. of the entire differences series was computed.

(5) The differences series was then progressively windowed. The window size was set to exactly include five "bars" i.e. five

grouping bases. Thus if a subject was found to be grouping to the base four, a window twenty points long would be used. The integer multiple five was selected to match the number of consecutive judgements made in the "passive" condition. The windowing process started at the beginning of the differences series.

(6) The mean and S.D. of the five bars within this window were then computed. Then every Nth point was sampled (N represents the grouping base) and the mean and S.D. computed. Then the leading edge of the window was advanced by one point and every Nth point sampled again, each sample commencing at the origin of the window. This process was repeated N times, until there was a complete set of N "firsts" in the bar, N "seconds", and so on.

The window was then reset to start at one point past the end of the previous window, and the entire process repeated. This continued until the number of points remaining in the series was less than the number required to fill a complete window.

(7) This process generated a series of means and S.D.'s., each computed over five consecutive bars. The bars selected did not necessarily correspond to the actual bars which the subject produced, as the start point was arbitrary (i.e. series origin). This required that a control process be employed. If a sample is taken across grouping boundaries, the inter-tap-interval variance might possibly be greater than if the sample is taken within a group (although this was not found by Vorberg and Hambuch (1978)). Therefore, in three randomly selected series, alternative start-points for the windowing process were employed and the

resultant profiles compared. No significant differences were found in the mean S.D.'s, so in the data presentation only those results that were generated by windowing from the series origin were used.

Summary of the selection procedure.

Thus the comparison is between the S.D. of selected offsets in five consecutive judgements of visual-auditory asynchrony in the "passive" condition against the S.D. of taps in five consecutive bars, i.e. five consecutive placings of the tap "first" in each bar, "second" in each bar and so on, according to how many beats were in a bar.

Analysis Procedure

The windowing process gave between twenty-eight to thirty S.D.'s. From these groups of S.D.'s it was then possible to calculate an average S.D., firstly for all the "firsts", "seconds", etcetera, and then an overall mean and S.D. for the entire condition.

Then a one-way independent ANOVA was done on the S.D.'s in each "active" condition. For example, a trial grouped by fours, with an N of twenty-eight would be analysed as four samples with seven observations in each sample. The ANOVA was done to determine (a) whether the most prominent inter-beat-interval grouping revealed in the Fourier transform was reflected in the variability ratio of the S.D.'s of those IBI's and (b) whether the "active" condition data variance could be pooled for the purposes of the main comparison.

More detail on these points is given below.

The appropriate test here is a univariant ANOVA rather than a multivariant because this investigation was concerned solely with main effects and not with interactions.

Note that the use of ANOVA, as with any parametric statistic, requires that certain assumptions about the form of the data be met. These are as follows.

(1) Scores must be measurements on a continuous numerical interval scale.

(2) Scores must be normally distributed, or approximately so. The easiest way to check this was by plotting the points. This was done, and the lack of excessive skewness checked.

(3) There must be homogeneity of variance. That is, the random variance must be evenly distributed. The simplest check is to compare the S.D.'s in each of the beat groupings. This was done. Overall, there was no obvious bias.

A certain measure of judgement was required for each of the last two points. According to Boneau (1960), a small degree of violation of these two assumptions is tolerable. Boneau notes, for example, that if the samples are of equal or nearly equal size (which in our case they are) and if the samples are of the same form as the underlying population distributions, then samples as small as five will give results for which the true probability of rejecting the null hypothesis at the 0.05 level will tend to be within .03 of this level. For example, at prestissimo, with both visual and auditory information present, the sample size is fourteen. For this, the assessed probability is likely to be within .01 of the 0.05 level.

Clear violations would have forced the use of the non-parametric equivalent, Friedman and Page's L Trend Test. The incentive to use parametric tests is that they are more powerful, and as the hypothesis involved testing a difference of means, it was more convincing to show a separation using parametric statistics.

Experiment Two: Results

In these "active" trials the data is subdivided by information modality (visual, auditory, and both visual & auditory), and tempo, and each condition is presented separately. All values, unless otherwise stated, are in ms. The data is in table six.

Table six

ANOVA of Production Condition S.D.'s.

Tempo: prestissimo. Information present: visual.

	N	Mean	S.D.
1sts	7	27.4	11.2
2nds	7	29.9	12.8
3rds	7	31.8	15.1
4ths	7	31.1	15.5

Tempo: prestissimo. Information present: auditory.

	N	Mean	S.D.
1sts	7	11.0	2.7
2nds	7	9.8	6.1
3rds	7	9.6	4.4
4ths	7	13.4	8.5

Tempo: prestissimo. Information present: both visual and auditory.

	N	Mean	S.D.
1sts	14	9.2	2.7
2nds	14	9.4	4.0

Tempo: moderato. Information present: visual.

	N	Mean	S.D.
1sts	7	29.8	13.0
2nds	7	31.6	10.2
3rds	7	32.6	7.1
4ths	7	30.4	8.6

Tempo: moderato. Information present: auditory.

	N	Mean	S.D.
1sts	7	16.3	4.2
2nds	7	13.8	6.3
3rds	7	16.3	4.3
4ths	7	11.8	4.8

Tempo: moderato. Information present: both visual and auditory.

	N	Mean	S.D.
1sts	7	16.9	5.3
2nds	7	17.0	6.7
3rds	7	15.6	7.6
4ths	7	12.4	6.4

Tempo: larghetto. Information present: visual.

	N	Mean	S.D.
1sts	15	31.4	10.7
2nds	15	30.8	11.5

Tempo: larghetto. Information present: auditory.

	N	Mean	S.D.
1sts	4	18.5	5.5
2nds	4	17.6	9.0
3rds	4	17.8	4.3
4ths	4	21.7	7.8
5ths	4	23.4	11.7
6ths	4	16.0	8.1
7ths	4	13.9	1.5

Tempo: larghetto. Information present: both visual and auditory.

	N	Mean	S.D.
1sts	10	21.6	10.4
2nds	10	21.6	8.7
3rds	10	19.0	7.8

Conclusions.

In every condition the Null hypothesis was upheld. In no case was there a significant difference between groups.

Control Analyses

Two control analyses were performed in order to ensure that the uniformity of variance was not an artifact.

Testing the procedure for producing the differences series.

The ANOVA of the differences series data grouped according to the bases suggested by the Fourier transform found no significant differences. One possibility that had to be checked was that some part of the analysis procedure, either the subtraction or the windowing and averaging process, had weakened the separation of groups, giving rise to the apparent lack of grouping of S.D.'s.

Figures 8.1, 8.2, and 8.3 show examples of tap series, plotted to the group base. The grouping effect can be clearly seen. The effect is significant to the to the .01 level at moderato amd prestissimo, but just fails at the .05 level in the case of larghetto.

Figures 8.4, 8.5, and 8.6 show the differences between the grouped means in the differences series. The separation between the grouped taps is much less clear than in the previous figures.

So the first check was to ensure that the uniformity of variance was not also due to the subtraction of the target series from the tap series. The apparent loss of the grouping effect upon subtraction of the tap series from the target series might mean that a sufficient fraction of the group-base peak in the total power spectrum is lost on subtraction, reducing the amplitude of the peak relative to general noise level. This could only be the case if a peak in the target series coincided with the peak in the tap-series, that is, if (due, for example, to a mechanical imperfection) the

Figure 8.1
Differentiated tap series means
Means and S.E.'s

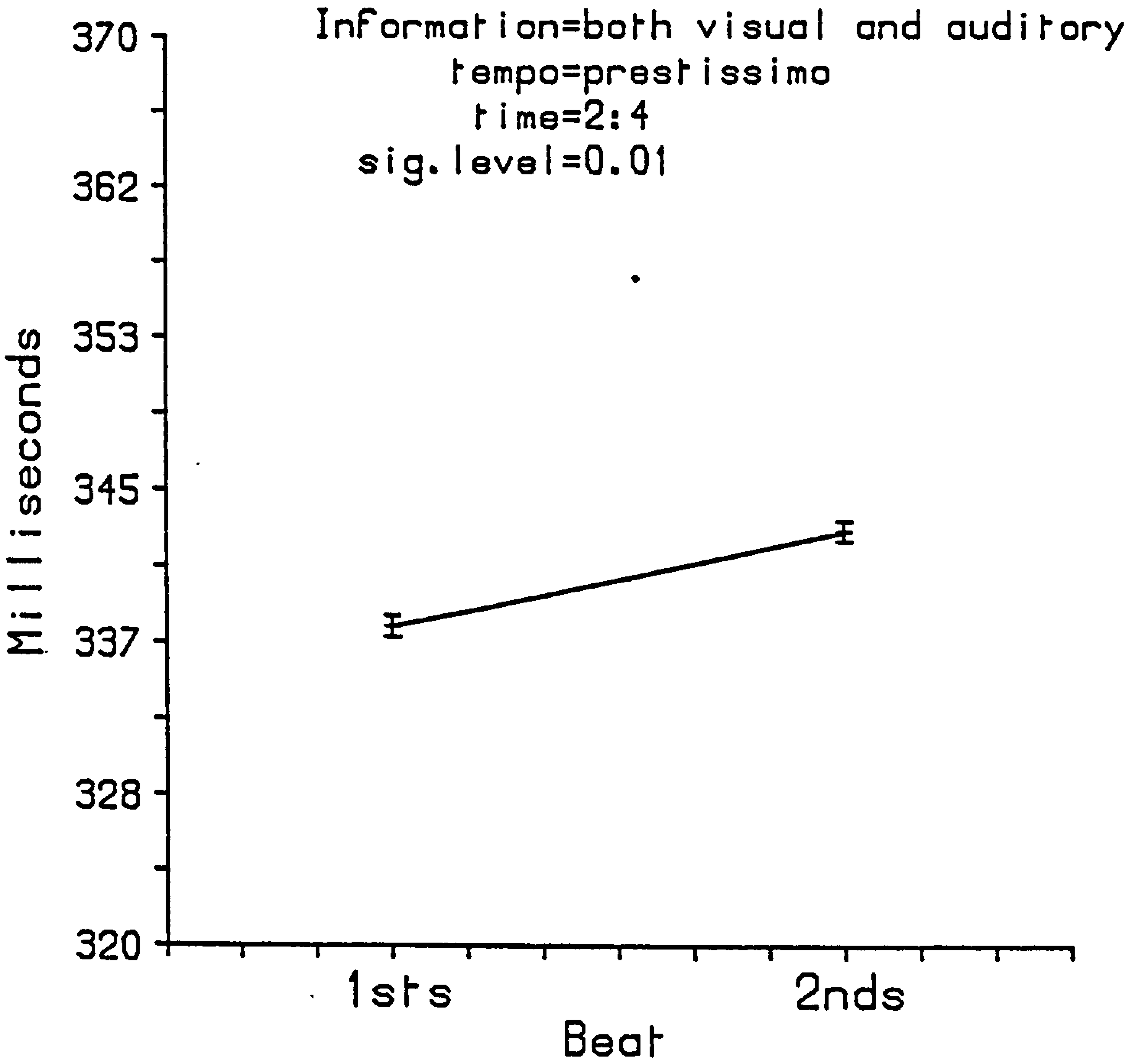


Figure 8.2
Differentiated tap series means
Means and S.E.'s

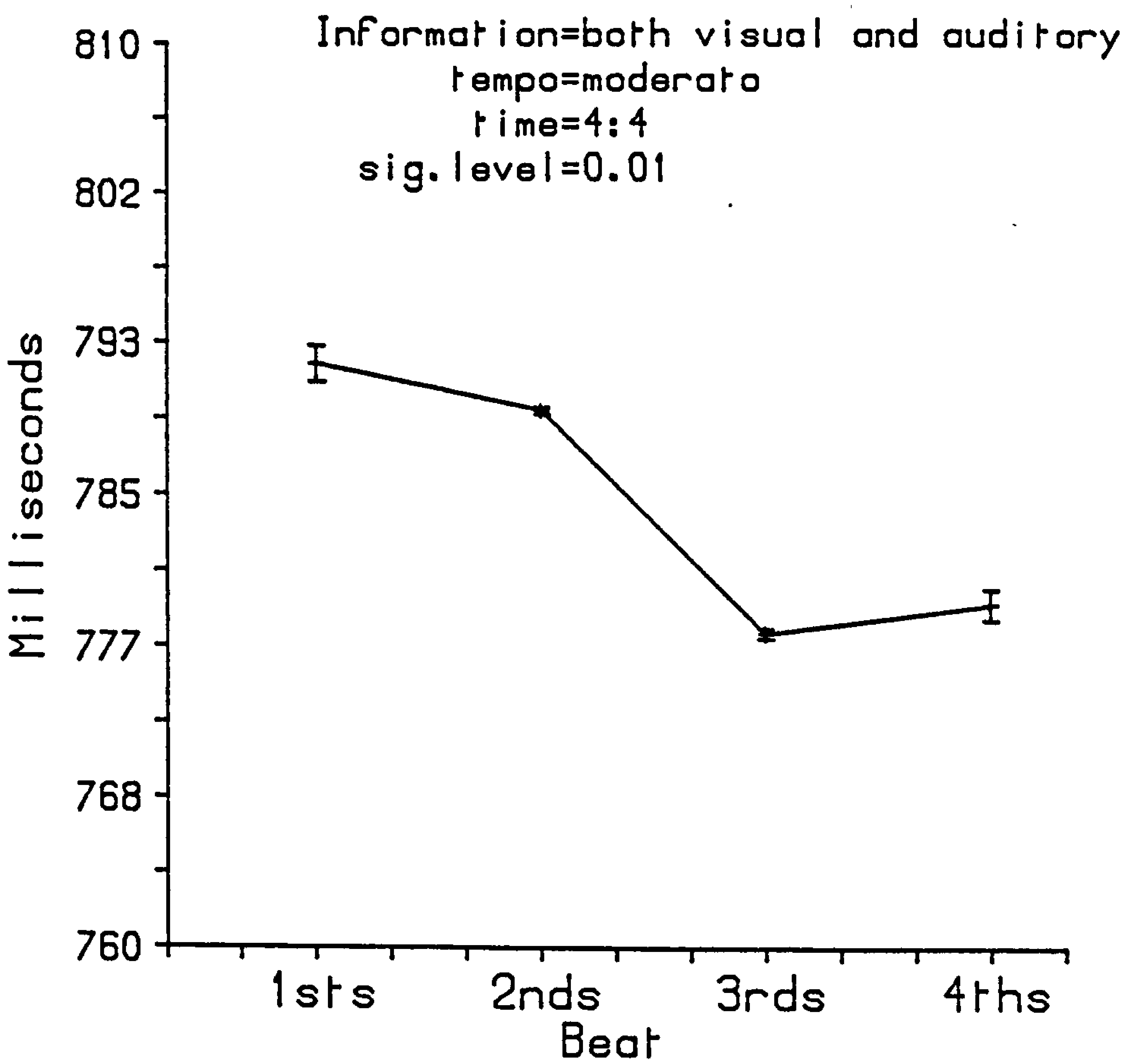


Figure 8.3
Differentiated tap series means
Means and S.E.'s

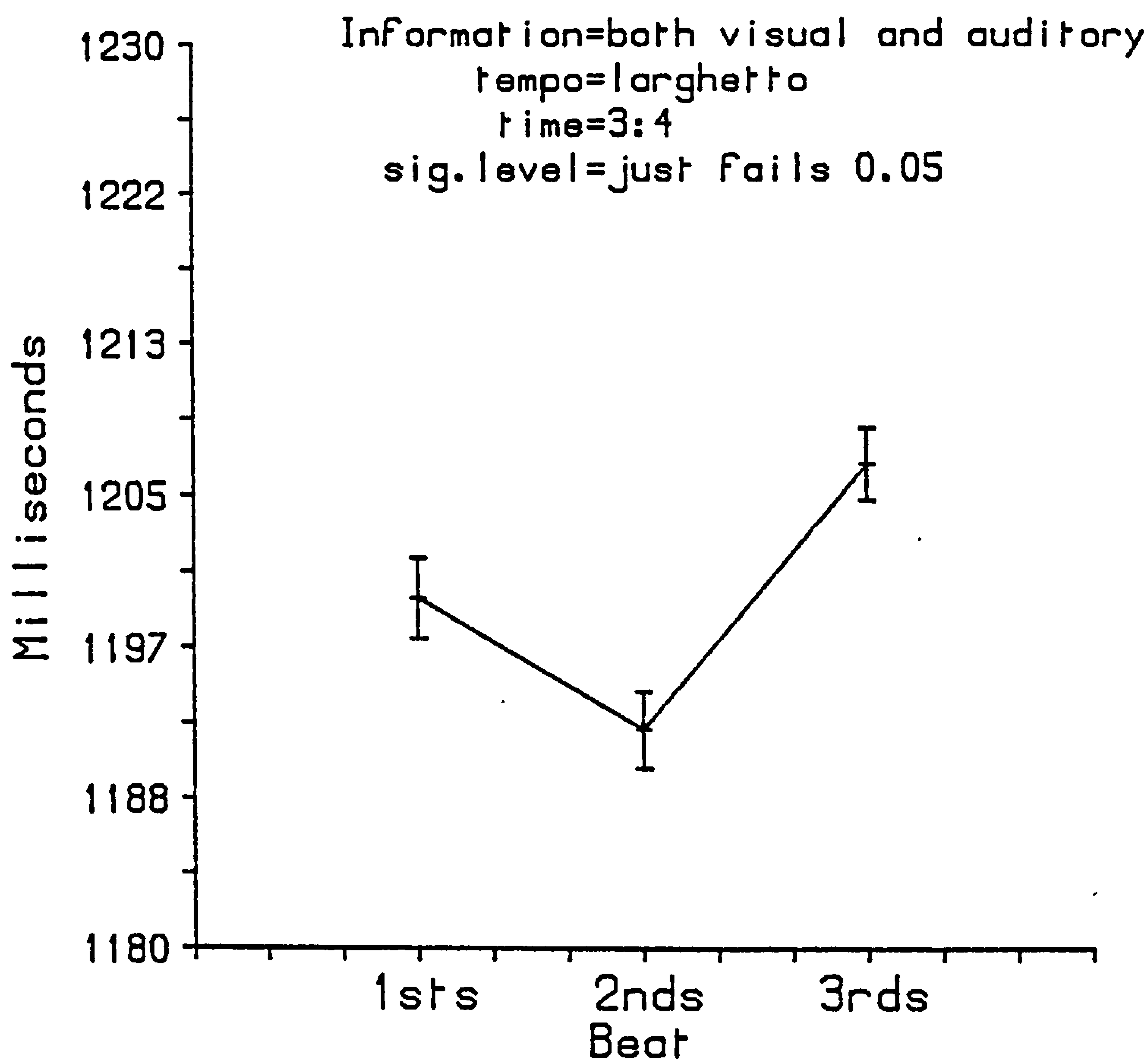


Figure 8.4
Differences series means
Means and S.E.'s

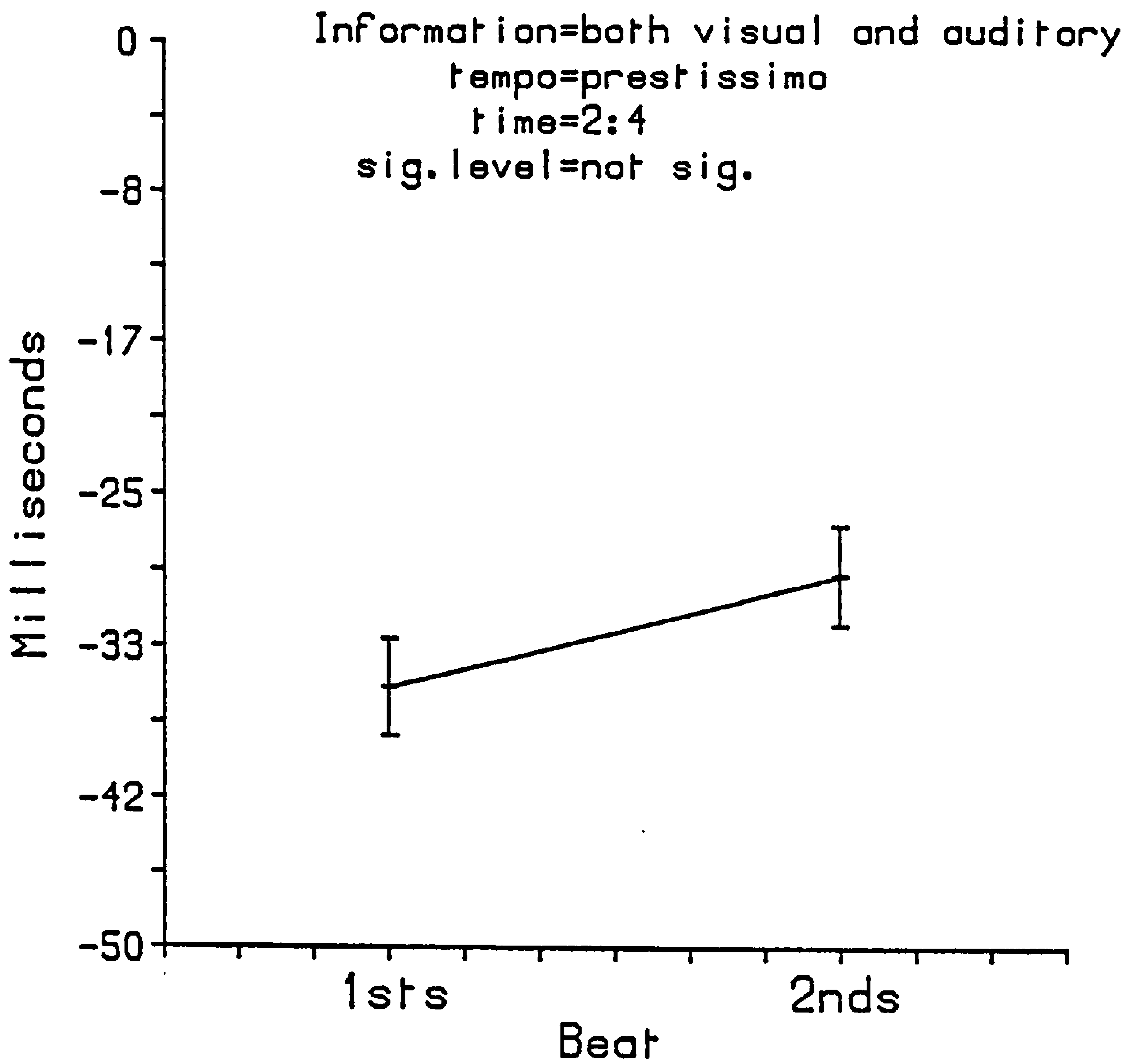


Figure 8.5
Differences series means
Means and S.E.'s

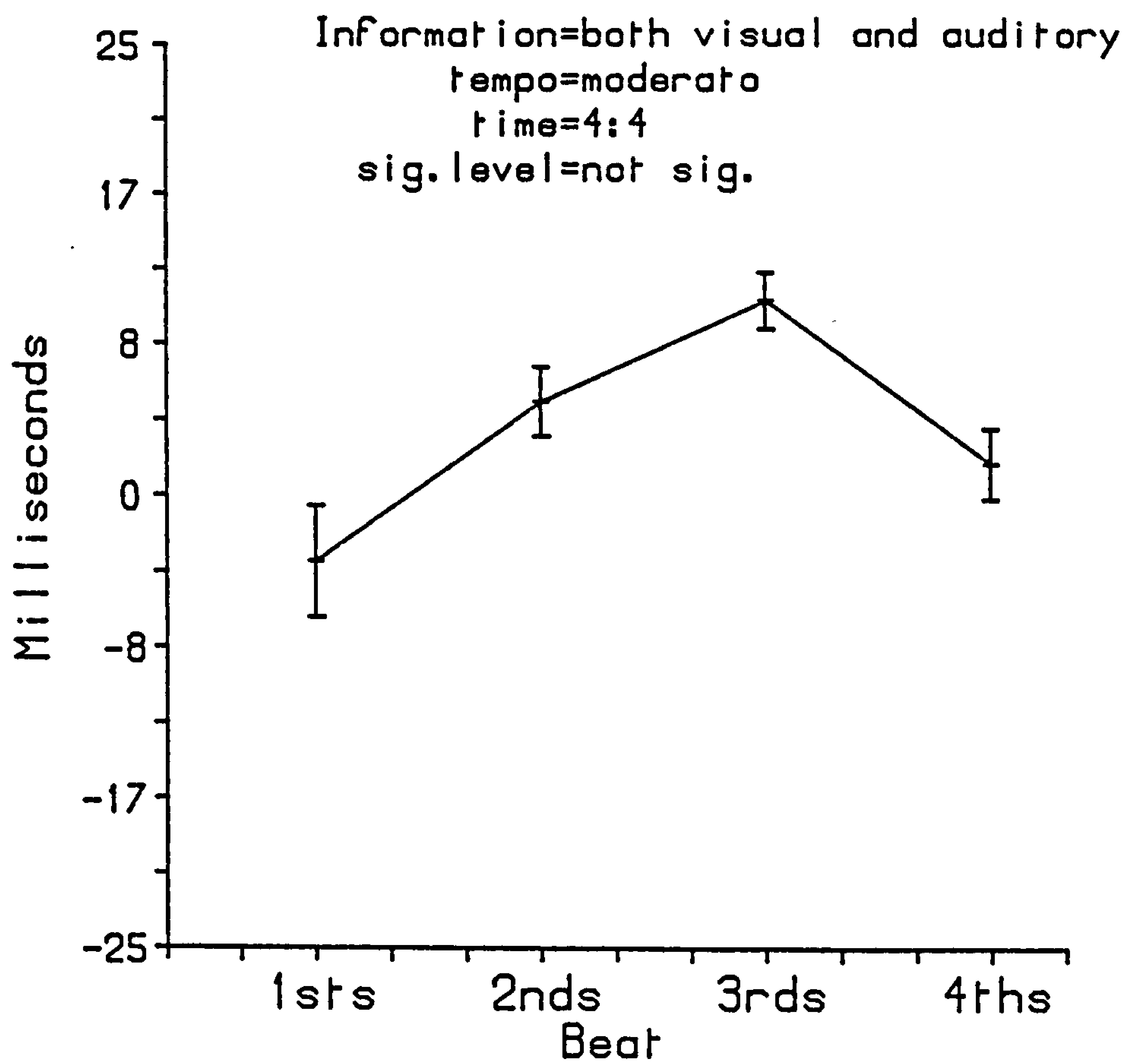
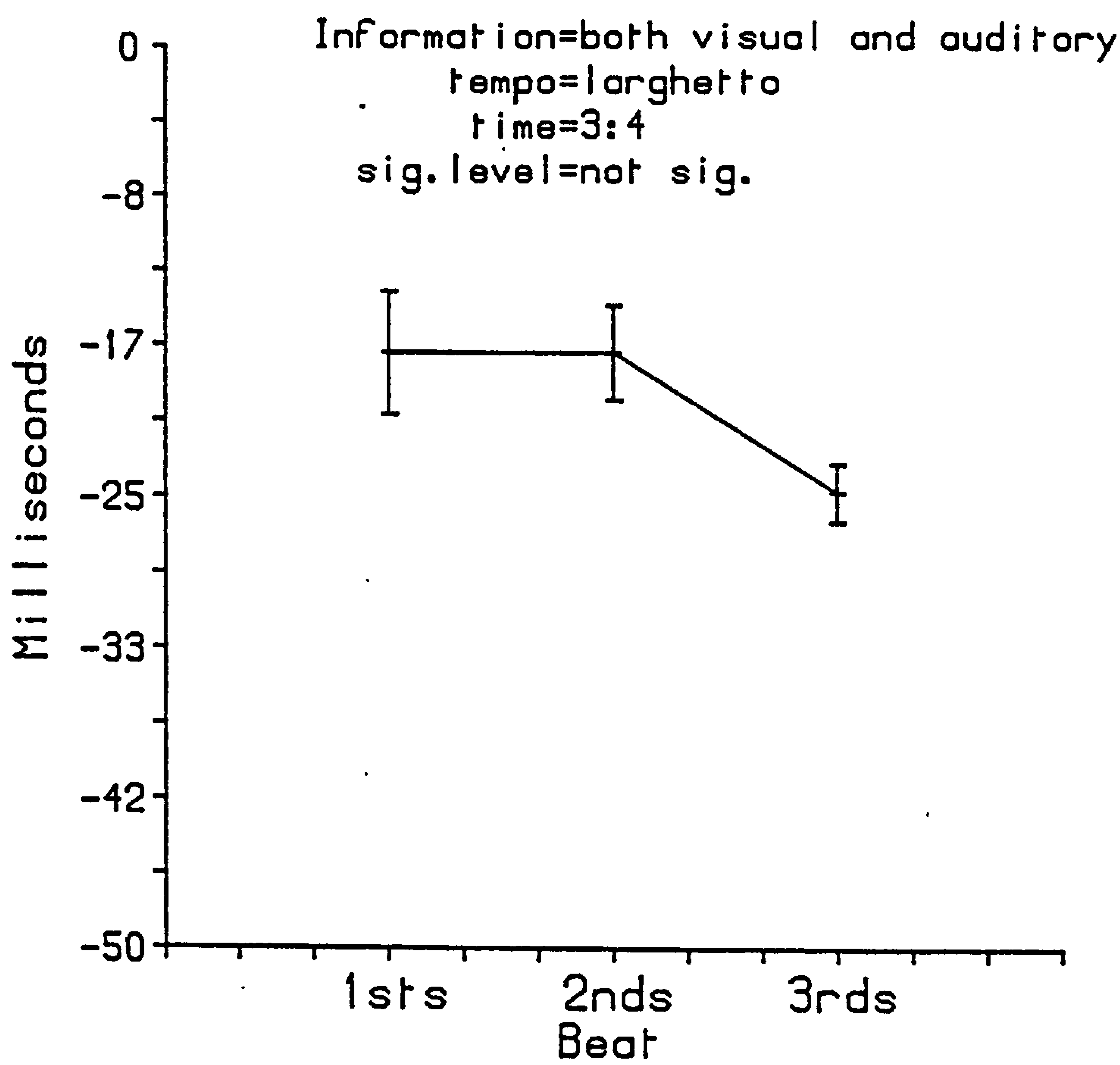


Figure 8.6
Differences series means
Means and S.E.'s



target series was grouped in a way similar to the tap series. On examination, the appropriate target series did indeed evidence grouping. The differences in inter-event-intervals were very small, typically 2 or 3ms, but their regularity ensured that the resultant "grouping" was visible above noise level. The subtraction process, in some cases, reduced the amplitude of the principal peaks in the Fourier transforms by about 20 or 30%, although the reduction was insufficient to obscure the peaks (this is why the transform of the differentiated tap series alone was used to identify the grouping bases). This raised the possibility that the grouping base observed was either derived from or else driven by a grouping derived from an irregularity in the target series. This possibility was examined in chapter seven. The conclusion was that this explanation cannot hold, because it can only account for those cases where there is a coincidence in power-peaks or grouping bases between target and tap series. Cases were observed where the groupings were not the same, and where there was no coincidence of tap and target peaks in the transforms. This means that the subtraction cannot always be the cause of the loss of significance.

Testing the Fourier transform procedure.

The second control for a possible artifact was to ensure that the Fourier transform procedure was not too powerful, and thereby indicating spurious groupings. In order to investigate this possibility, ANOVA's were performed on three data sets. The sets were selected to represent a cross-section of all variables. There was one from each tempo; all were recorded while both visual and auditory information were present, and the prestissimo trial was a 2:4 beat, the moderato trial a 4:4 beat, and the larghetto trial a 3:4 beat. The ANOVA was performed on both the grouped raw data (IBI's) and the grouped means. The ANOVA demonstrated that the grouping effect gave results significant to the .01 level at moderato and prestissimo, although the trial at larghetto just failed to reach the .05 level.

Thus it follows that the Fourier transforms were of an appropriate order of power and the distinctions they revealed were also found by an ANOVA. Further analysis exonerated the windowing and averaging procedure. ANOVA's before and after achieved exactly the same level of significance.

The problem therefore remains of how to account for the loss of significance of the separation between means when the tap series is subtracted from the target series.

The answer proved to be that the loss of significance was only apparent. Figures 8.7, 8.8, and 8.9 show the plot of the mean differences series, each mean computed over five raw data points. This, of course, is equivalent to smoothing the curve. This figure clearly illustrates the true story, which is that a particular grouping cluster is maintained while the cluster drifts at low frequency relative to the target series.

The reason why the grouping effect is apparently lost is as

Figure 8.7
Differences series
Means of five points

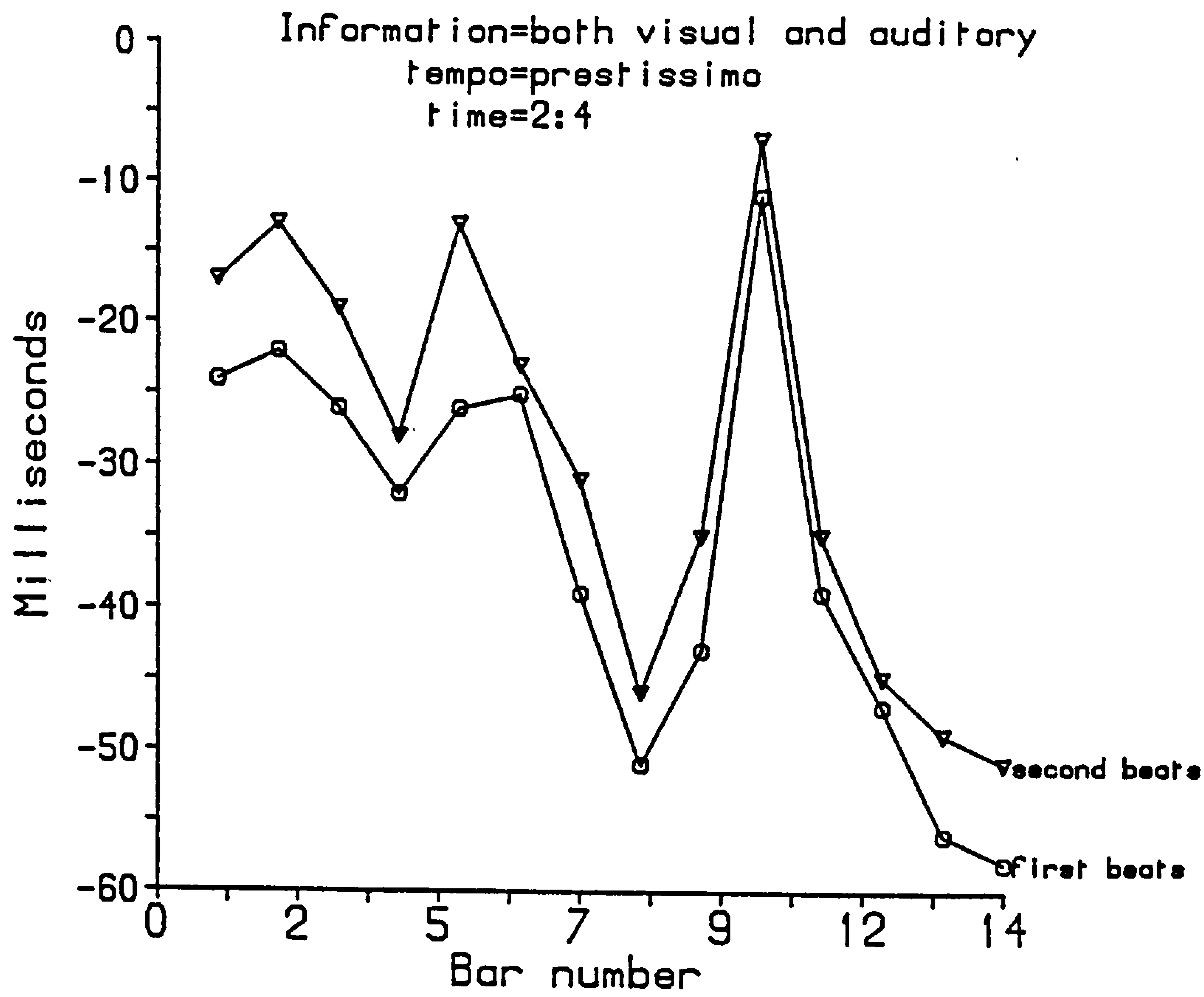


Figure 8.8
Differences series
Means of five points

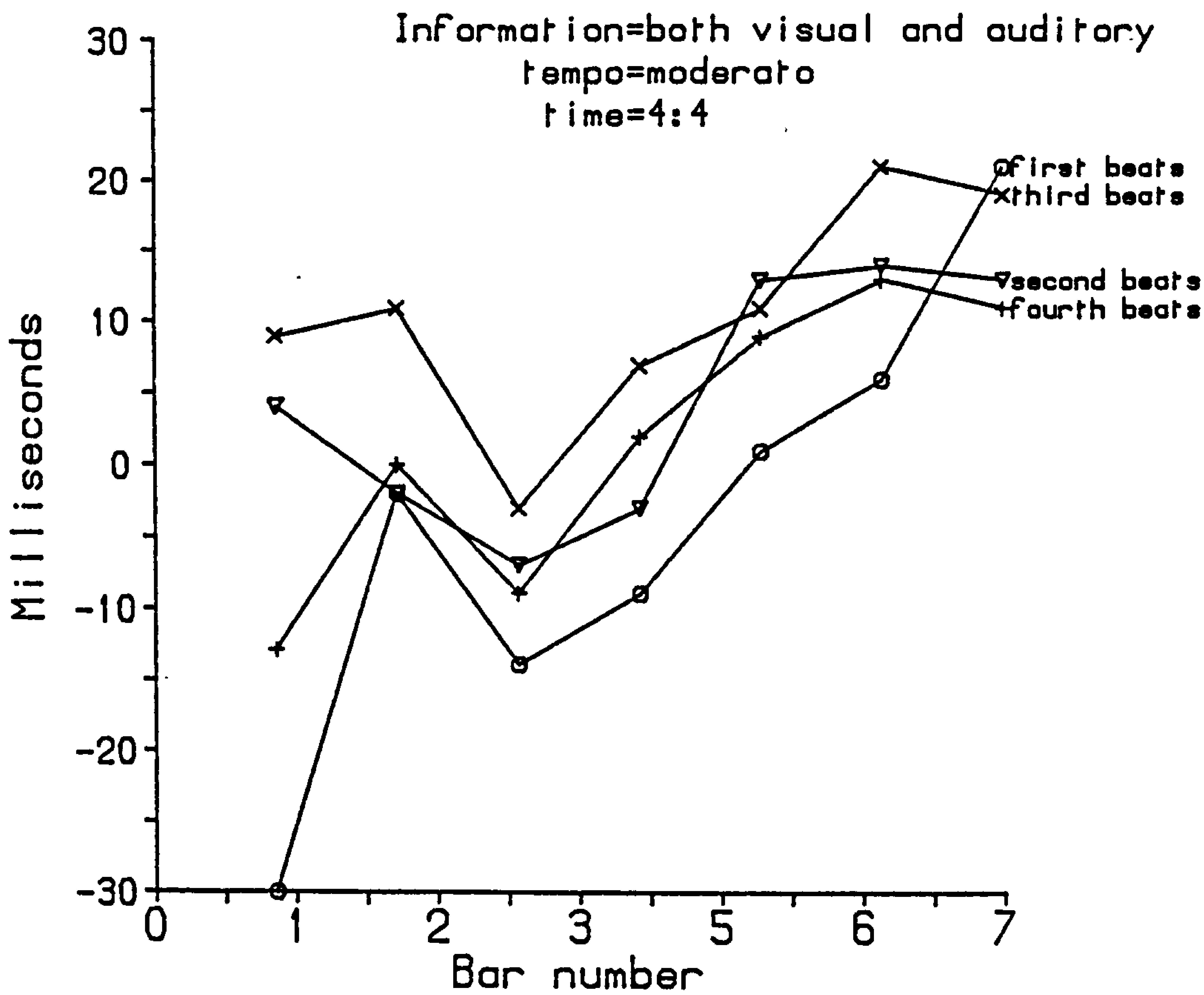
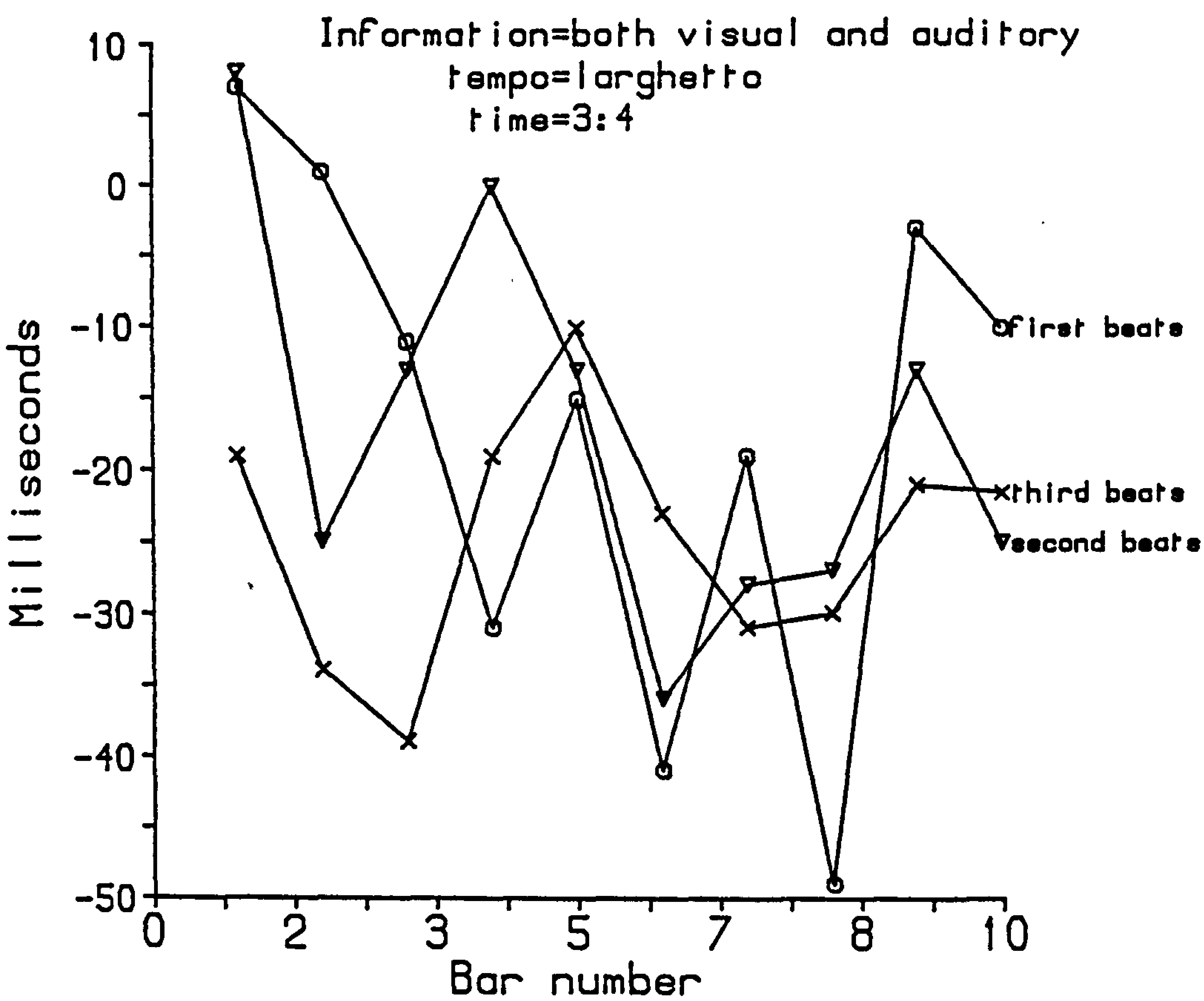


Figure 8.9
Differences series
Means of five points



follows. The differentiation of successive points to generate the series shown in figures 8.1, 8.2, and 8.3 effectively "loses" the low frequency components of the total energy spectrum revealed in the Fourier transform. This allows the grouping of these points to be observed. With the differences series, on the other hand, where the tap series is subtracted from the target series to observe the offsets, all the low frequency drift comes through and "swamps" the contribution of the grouping effect.

The explanation can also be given in terms of the ANOVA. The variance of each "column" or grouping-set is far greater with a large low-frequency drift than the regular difference across the "rows" or bars. Thus the grouping effect is "swamped".

The conclusion is that in the mean differences series the separation is still significant in actuality, and the grouping order revealed in the differentiated series is preserved when the tap series is subtracted from the target series.

The fact that the contribution is swamped by low frequency drift is in itself interesting. What it demonstrates is that the grouping phenomenon is sufficiently robust for the effect to obtain while the "production" series as a whole is accelerating or decelerating relative to the target series. The grouping is therefore clearly not determined by the target series, and this provides further evidence for the contention that grouping is endemic or inherent to tap production.

This analysis also demonstrated that the Fourier transform procedure will elicit genuine grouping when an ANOVA will fail to do so. If there is low-frequency drift or a phase-shift in response grouping, this will cause loss of significant separation in an ANOVA. This is because the variance of each column, which corresponds to the individual beats in a bar, is far greater with a large low-frequency drift than the regular difference across the rows, which correspond to the bar structure. Thus the grouping effect is masked. As the component periodicities are separated out with a Fourier transform, this grouping may still be observed.

Discussion.

Two conclusions may be drawn from this experiment. The first conclusion is that the group-base contributions shown in the Fourier transformations of the tap series are clearly not reflected in the S.D.'s of the individual beat offsets averaged over five bars. In other words, the S.D.'s of the averaged grouped beats are not themselves grouped. This is shown in figures 8.10, 8.11, and 8.12. This plots standard errors around each S.D. The overlap indicates that there is no difference between the S.D.'s. Irrespective of the fact the the firsts, seconds, etcetera, are clearly and consistently of different average lengths, the consistency that the subject achieves in placing each of these beats in a bar is uniform throughout. That is, no beat is more precisely located than any other. This supports the hypothesis that in the situation where the target series does not itself vary, the grouping observed reflects the operation of the muscle synergy deployed.

The second conclusion follows from the first, that as the separation of the groups of S.D.'s has not been upheld, it is now possible to pool the variance of all the "beats" in the "active" condition for the purposes of comparison with the "passive" condition.

Figure 8.10
Differences series S.D.'s
Means and S.E.'s

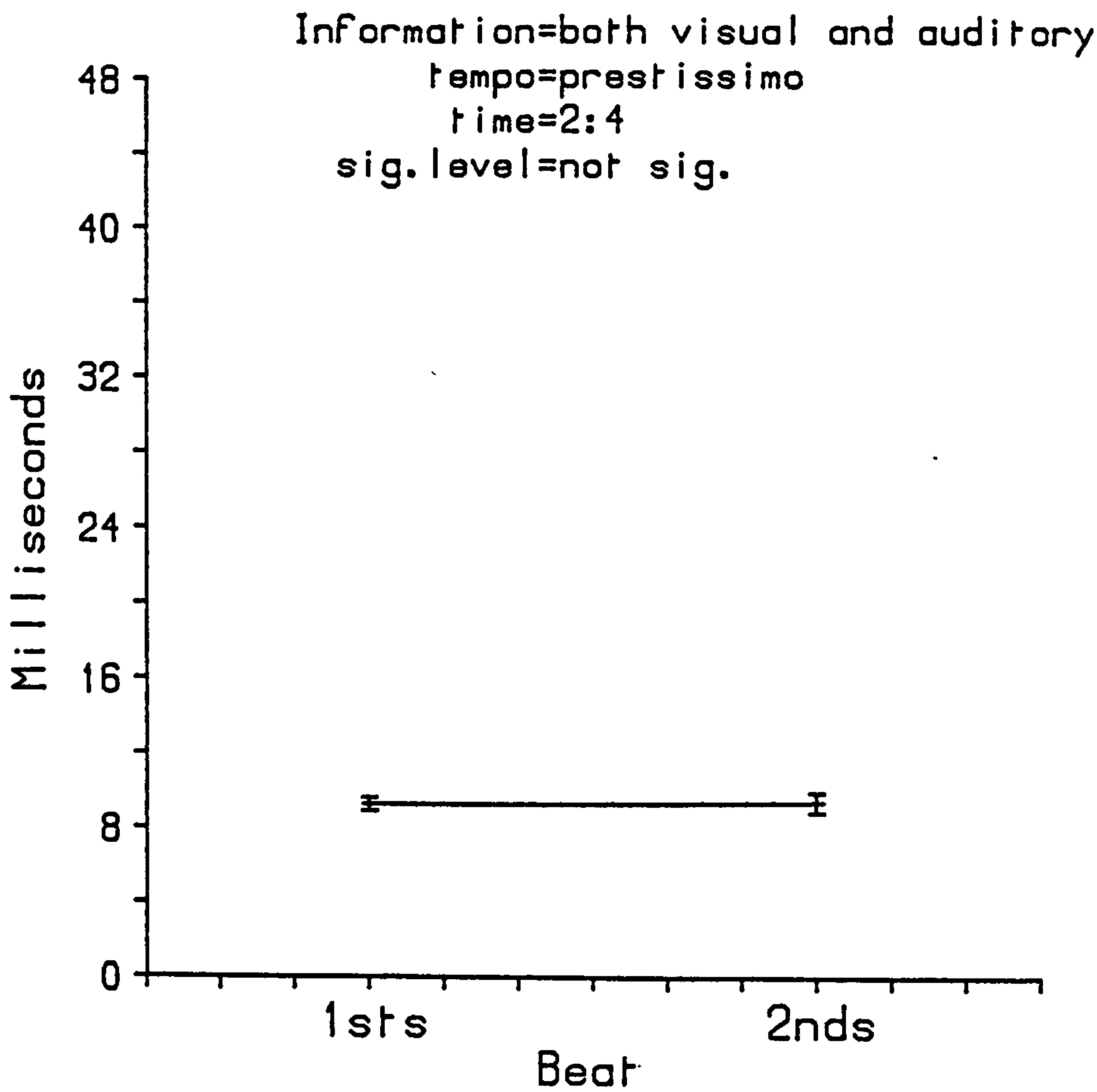


Figure 8.11
Differences series S.D.'s
Means and S.E.'s

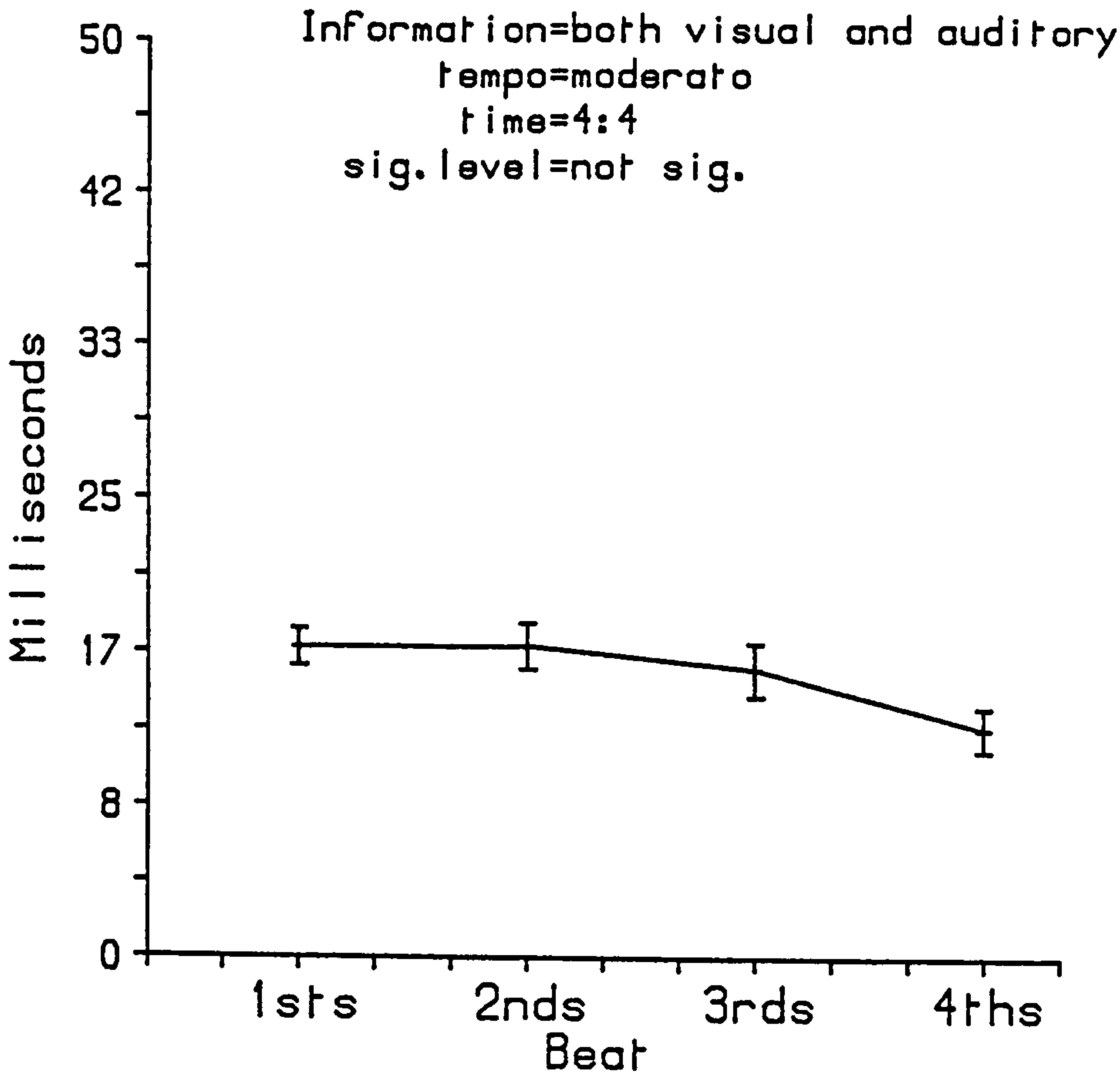
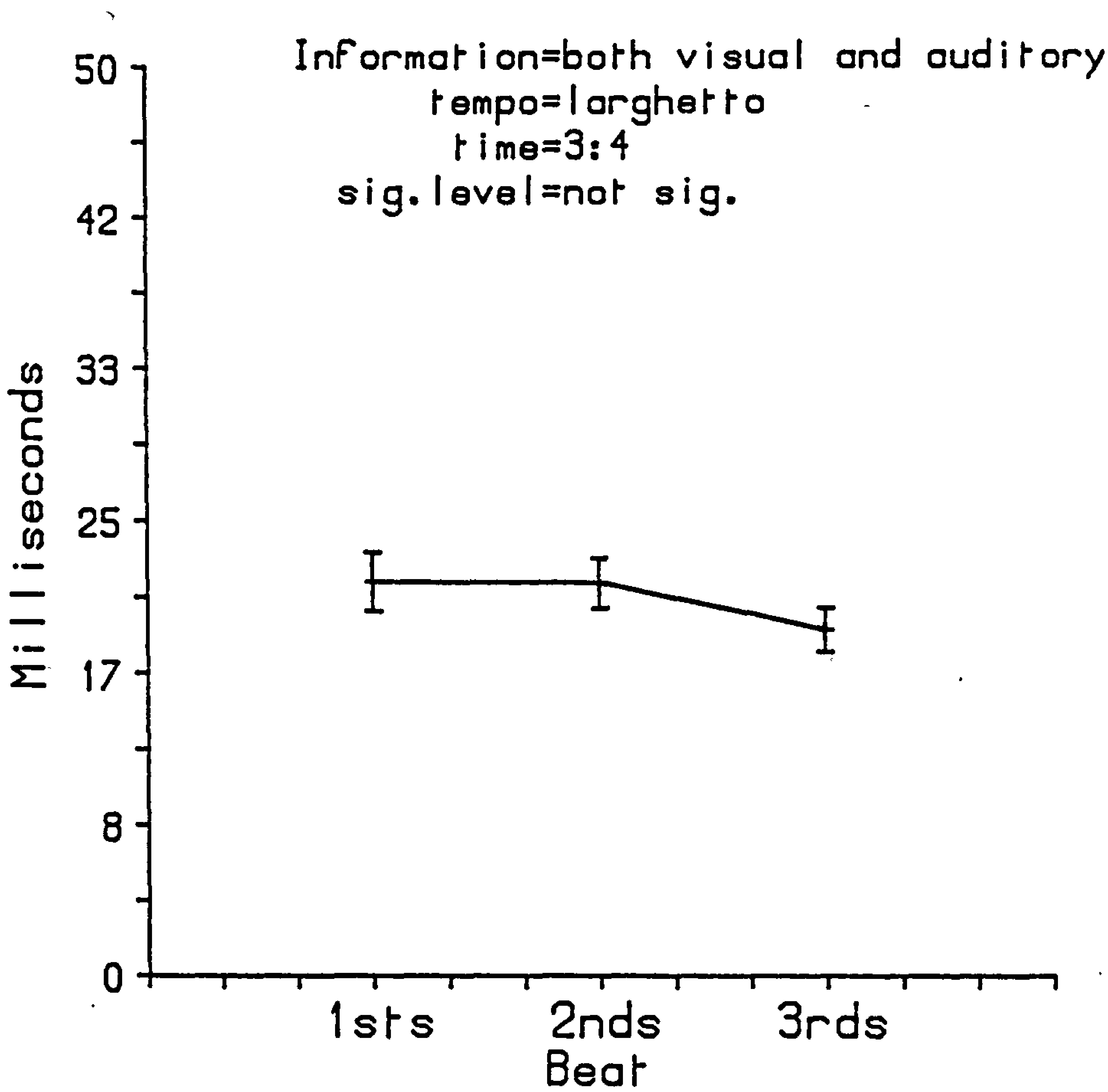


Figure 8.12
Differences series S.D.'s
Means and S.E.'s



Experiment Three.

The comparison of "active" and "passive" judgements.

The comparison procedure was determined by the nature of the data. In the "passive" conditions there are five consecutive attempts to achieve a self-selected degree of offset between a visual and an auditory event, and one S.D. is calculated over these five points.

As has already been noted, one of the conclusions of chapter six was that while the initial degree of offset was arbitrarily selected, once selected it could be replicated. This means that the use of t-ratios, which would require computing the difference between means, would not be appropriate here because in the "passive" condition the means vary enormously between sets of trials, while the S.D.'s within trials remain very small. It is, of course, the S.D.'s that are important here. They indicate the accuracy with which the subject can replicate a judgement in different conditions.

The test, therefore, is whether the single S.D. in the "passive" condition falls within a given critical range of scores around the mean S.D. in the "active" condition, thus indicating that it probably lies within the same population This required that the single S.D. be treated as a sample mean and testing the difference from the population mean from the "active" condition. The alpha level adopted was the .05 level of significance. The hypothesis is unidirectional, that the S.D. in the "passive" condition will be significantly less than the mean S.D. in the "active" condition.

The confidence limits for the "active" distribution were calculated. The formula used was one devised for small samples and described by Downie and Heath (1974). The standard error was calculated by dividing the standard deviation of the scores in each condition by the square root of N-1. This was then multiplied by the t value at the appropriate number of degrees of freedom, with an alpha level divided by two (because the prediction is directional, and the test therefore one-tailed). The score in the "passive" condition was then measured against these confidence limits, in effect converting it into a z-score.

Data Selection

It was necessary to examine the data for dubious points. The procedure, for each of the main conditions, was as follows.

"Passive" condition.

There were three successive trials at prestissimo (see chapter six). The S.D.'s of the five successive judgements in each trial, in order of size, were 0.8, 1.6, and 6.6 respectively. If the one "wild" judgement in the second trial is included the largest S.D. is 22.9. It is clear that the 22.9 figure is not typical of the size of S.D.'s in the "passive" condition, as it is so much an exception to the others, and exists because of a judgement in which the direction of offset was reversed. The 22.9 figure must therefore be regarded as dubious, which leaves the figure of 6.6 as the largest valid S.D. in the "passive" condition.

There is only one doubtful data point at moderato. Its exclusion has the effect of reducing the S.D. from 7.0 to 4.5. This is not significant as it does not affect the clear separation of the groups achieved with the larger figure.

"Active" condition.

In the "active" condition, where there was any possibility that a single erroneous judgement had increased the size of the S.D. in that trial, the S.D. was recomputed excluding that point. As a control, the lower figure was then tested in the comparison. This was done because taking the lower figures provided the stronger test of the separation of the two populations, making a type I error less likely. In no case was this found to affect the results, so in this second data presentation only the full data sets are given.

The data for comparison is in table seven.

Table seven

Tempo / Modality: Prestissimo. Visual.

Condition	Sample	Mean	N	SE
Production	-	30.0	28	2.5
Perception	6.6			

Prestissimo. Auditory.

	Sample	Mean	N	SE
Production	-	10.9	28	1.1
Perception	6.6			

Prestissimo. Both visual and auditory.

	Sample	Mean	N	SE
Production	-	9.3	28	0.7
Perception	6.6			

Moderato. Visual.

	Sample	Mean	N	SE
Production	-	31.1	28	1.8
Perception	7.0 or 4.5			

Moderato. Auditory.

	Sample	Mean	N	SE
Production	-	14.5	28	1.0
Perception	7.0 or 4.5			

Moderato. Both visual and auditory.

	Sample	Mean	N	SE
Production	-	15.5	28	1.2
Perception	7.0 or 4.5			

Larghetto. Visual.

	Sample	Mean	N	SE
Production	-	31.1	30	2.0
Perception	11.5			

Larghetto. Auditory.

	Sample	Mean	N	SE
Production	-	18.4	28	1.4
Perception	11.5			

Larghetto. Both visual and auditory.

	Sample	Mean	N	SE
Production	-	20.7	30	1.6
Perception	11.5			

Conclusions.

The demarcation of result profiles is extremely clear. Every comparison is significant to the 0.001 level.

Discussion.

In the "passive" condition the S.D.'s are consistently smaller than in the "active" condition. When the subject has only to make successive judgements of asynchrony he can replicate a given asynchrony with greater precision than when he has to attempt to reproduce a given interval by manipulating a tapswitch. Therefore, as there is an increase in error, the addition of the effector operation must reflect the introduction of an additional source of variance.

The various models that have been reviewed in this and the previous chapter would account for this finding in different ways.

The two-stage model of Wing and Kristofferson (1973b) involves a central timer and a response generating mechanism, each with associated error variance. This model would predict that the addition of the production dimension would add a further, independent, source of error which would reflect in increased variance. Some of the limitations of this model were discussed in chapter seven.

It is also possible to account for this finding in terms of the frequency driver plus muscle synergy model of Kelso et al (1983), which is also a two-stage model but does not suffer from similar limitations.

To successfully reproduce a given interval must entail the perception of that interval, and the underlying process may well be similar. That is, the perception of a given IBI may be represented in the same form as the instructions for the organisation of a responding muscle synergy. This would have the advantage of parsimony. If representation is thus equivalent, then this would explain the readiness of people to fall into step with a rhythm, as between the perception and the action there would remain only the activation of the organisational representation.

The additional variance associated with the production condition must then reflect the operation of the attempt to synchronise and the according regulation of the synergy.

This concept of the nature of rhythm in music has some similarity to that of affordances, in that the operations of perception and action appear fundamentally integrated, possibly being represented in the same terms.

Experiment Four.

Tempo and accuracy.

Introduction

In chapter seven it was stated that there were two reasons for varying the number of markers on the disk. One was to ensure that the subject's choice of grouping base was not being artificially determined. The other, independent, reason for varying the number of markers on the disk was as follows. The requirement that different numbers of markers be used whilst keeping the chosen tempo constant meant that the disk had to be set to run at different speeds (see the methods section of chapter seven). This allowed a further investigation of the relationship between tempo and accuracy. A consistent variation in accuracy of tap placement by disk speed would suggest that the absolute speed of the disk (and therefore the brevity of the events with which the subject had to synchronise) determined the limits of the subject's ability to synchronise a tap with the coincidence of two disk markers, rather than the inter-coincidence interval.

Methods

The general procedure was as described in chapter seven. The index of accuracy of tap placement was taken to be the size of the S.D. of the subject's tap series under the various conditions.

The test selected was the Walsh test (Siegal, 1956), on the basis that the scores are normally distributed, so parametric statistics are inapplicable. However, it is necessary to assume that the samples are drawn from symmetrical populations. The Walsh test entails that for each set of data, the mean should tend towards the median. The number in each category is four, the directionality of the prediction entailed a one-tailed test, the significance level was therefore .062.

Results

Table eight shows the S.D.'s recorded in each condition.

Table eight

Condition	Speed Fast(3)	Medium(4)	Slow(5)
Visual	27.6	29.5	32.2
Auditory	32.9	20.4	20.9
Both vis&aud	22.6	20.0	17.9
No target	20.6	26.0	30.6

Each category was tested against every other in turn. No significant differences were found. It should be noted that the Walsh test is very power-efficient, so that although the sample is small this conclusion is most likely correct.

Conclusion

Clearly, the absolute speed of the disk is not what determines the variability of the subject's responses. There is no consistent effect across the different conditions. Thus it must be the inter-beat-interval or tempo that is related to the accuracy of synchronising movements rather than the actual duration of the target synchronies.

Discussion.

The relationship between tempo and accuracy has been noted in several previous chapters. From Bartlett and Bartlett's study it is clear that the relationship is broadly U-shaped, with responses at extremely rapid tempi being essentially random and with accuracy at extremely slow tempi being limited by the accuracy of the internal representation of the IBI. From the study described in chapter four it appears that the preferred range lies between 340ms and 1200ms. These figures are in accord with those of Povel (1977, 1981), who places the limits for internal representation of beat intervals at 250ms and 1500ms respectively. Woodworth (1899) and Vince (1949) have shown that as movement rate increased, movements bacame "ballistic" with less margin for the utilisation of feedback. Woodworth and Schlosberg (1954) have estimated that 250ms is required to process visual information in order to correct an action. Keele and Posner (1968) place this estimate at between 190ms and 260ms. These figures are in accord with Povel's upper limit, although the underlying explanations are different.

With regard to the actions required to synchronise with external events, Poulton (1974) found that subjects in a tracking task lagged by about 120ms behind the target, even with preview. Elkind (1956), however, found that preview allowed a reduction in this delay to around 40ms, thus there is clear evidence that pre-preparation of movements can reduce the asynchrony between event and action.

Musicians, of course, play at tempi outside of Povel's range, and possible strategies described include using subdivisions (of long intervals) or combinations (of short intervals) to bring the operative beat back within this preferred range. McElheren (1966) suggests that a conductor may subdivide anywhere within a bar when the tempo is slowing and

"the beat is becoming unwieldy."

Within the preferred range there are clear indications (see chapter two) that the nature of the relationship between synchronising accuracy and tempo is different to that outside the preferred range, being essentially linear. Thus the zone that Bartlett and Bartlett described as asymptotic is revealed to have a positive slope. This was obscured by the coarseness of their measures, and the use of pre-defined categories of tempi.

Why this linearity should obtain has already been discussed in chapter two. One possible explanation that was not mentioned in chapter two is that the linearity might be determined by the operating features of the muscle synergies deployed. That is, if muscle synergies manifest the properties of limit cycle oscillators, then there might be preferred frequencies, those that could be achieved with the minimum of additional control. The non-preferred (slower) frequencies might require additional control to introduce the necessary delays and thus achieve the desired tempo, and this could be the source of the additional variance observed.

Chapter Nine

The Transition from Homocentrism to an Ecological Perspective

Abstract

This chapter reviews the main findings of my programme of research and evaluates them in the context of the model of motor coordination in musical performance that was developed in chapter one. Implications of this model are then discussed and research strategies contrasted. The emergent paradigm, based on an ecological philosophy, is outlined and its implications are reviewed.

Introduction

In chapter one the three basic stages of the making of movements in musical performance were described, with the first level being defined as that of intention, the second being that of the control system that constructs a hierarchy of abstract representations of intended actions, and the third being that of the performance grammar of the motor system that generates the sequencing and timing of movements. This model was discussed in the context of the biological, physical, psychological, and cultural environments in which it operates.

This concluding chapter reviews the results reported in chapters two to four, and six to eight, and concludes that they support the model of motor coordination in musical performance developed in chapter one. The results are discussed in the context of the identified levels of the motor actualisation process, starting with the level of the motor programme and the biological and physical constraints, and ending with the concept of intentionality within psychological, interpersonal, and cultural environments. It becomes clear that the study of musical skills must include aesthetics. The remainder of this chapter reviews the problem this creates for a reductionist approach, concludes that the problem is inherent in that methodology, and suggests a future research paradigm.

Discussion of Results

Certain of our findings reflect psychophysical constraints. The relationship between tempo and accuracy of action timing, reported in chapters two and four and discussed in detail in chapter eight, has proved to be broadly U-shaped, but it is linear within the preferred range of IBI's from circa 300ms to circa 1200ms. The limits to accuracy outside this range are imposed by different constraints at the upper and lower end. At the upper, or fast, end of the range, responses become essentially random. This is because there is insufficient time to process visual information to correct an action. At the lower end of the range accuracy of response becomes increasingly limited by the accuracy of the representation of the IBI. It is possible that this loss of accuracy might plateau as more complex representational strategies, such as conscious counting, are brought in to play.

We conclude that the preferred range of the IBI's in musical performance is set by perceptual and representational limitations.

The linearity that obtains in the preferred range reflects the characteristics of the muscle groupings employed in the task. Slower movements require fewer motor units, and there is evidence that it is more difficult to operate a smaller number of units in a consistent fashion. This may be accounted for by the fact that with a small number in a group, the average of that group (which may be considered as some output function) is disproportionately affected by the aberration of one member. With a large number in a group, the average output will not be affected significantly by perturbations in individual contributions. Thus slower frequencies entail additional demands in terms of the control required.

While these limits are of fundamental importance in motor coordination for single motor components, they can be circumvented in the musical performance as a whole. Musicians do play at tempi outside the above limits by subdividing long intervals and combining short intervals to bring the resultant beat unit back within the preferred range.

Other findings that reflect psychophysical constraints include, firstly, the demonstration in chapter eight that auditory temporal acuity is greater than visual temporal acuity, and, secondly, that active tracking is more variable than a series of single perceptual judgements. The first fact underlies the definition of priorities for movement targetting discussed in chapter two; musicians derive their precise temporal targets from an auditory source (the ensemble) in preference to a visual (the conductor).

The second finding indicates that, while perception and action are intimately interrelated, they are not the same; each contributes its own error variance to the task.

Finally, results reported in chapter seven indicate that, in the production of a repeating series of movements, the muscles may be organised to contract as a functional grouping or synergy that may exhibit some of the characteristics of a limit cycle oscillator with a certain resonating frequency. It is possible that this characteristic is exploited to create a resonating frequency appropriate to the task at hand. This may be utilised as an element of a musical performance.

The majority of findings concerning musical performance must be considered in terms of what they reveal about the organisational level of structure, and their implications span the range from the biomechanical to the intentional.

The organised motor system is quite clearly capable of considerable accuracy. In chapter six it was demonstrated that the repeated selection of an offset between events could be done with considerable accuracy, showing an S.D. of only 0.8ms over five trials. The results reported in chapter four confirm that the degree of synchrony on the beat between a conductor and a musician was also very high, with a S.D. of 36.3ms for differences on the beat. As asynchrony covaries with tempo, accuracy can be considerably greater within a part of the range of tempi. At prestissimo the S.D. of differences on the beat was measured to be 10.0ms. The findings of chapter six and four together confirm; first, the separability of the error factors due respectively to perceptual and motor processes, second, that the motor component is the greater contributor to the error variance observed, and third, that musicians can achieve a remarkably high precision.

The average absolute difference between the conductor's beat and the musician's drum action at prestissimo was only 21.5ms, which is half the figure assessed by Elkind (1956) as being the average delay between the target and the subject's response in a tracking task with preview. It is not therefore possible to consider musical performance simply as the solution of a tracking task, even allowing for the benefit of preview. It is clear that only an active anticipation of and extrapolation from current information could allow the precision observed.

In the coordination of motor events for this performance the system is capable of monitoring and assimilating information up until the initiation of any ballistic phase of movement that might be required, for example, to achieve a given terminal impact velocity.

The clear distinction between approximating and goal-directed phases of movement observed in chapter four indicates that information could be incorporated in the planning of action up until circa 70ms before note onset. As this is less than the time required for visual processing and assessment of error, it is clear that the goal-directed phase should be considered as the culmination of a longer phase of progressive targetting, rather than as a distinct and separately-organised phase.

Thus the first set of conclusions is that conductor and drummer must be considered as engaging in an effectively continuous tracking and monitoring process, that information is being constantly assimilated and that the organising system must be capable of constant and rapid reconfiguration.

It became clear in chapter four that the monitoring of current position and velocity of the conductor's baton must be done within a framework which parameterises the baton action, and that this framework must be to some extent established prior to the event. This must be so because some elements of the baton action are essentially arbitrary. The fact that start time and tempo may be derived differently by different players from the same conductor (discussed in chapter two), in an analogous way to that in which an initial offset between transmodal events may be arbitrarily selected (as demonstrated in chapter six) may be presented as evidence for this. Some elements, such as the use of the vertical minima to delineate the beats in the baton trajectory (discussed in chapter three) exploit our normal or common perception of the effect of gravity. The schematic representation in the baton action of features such as grandeur by a process of scaling (demonstrated in chapter four) also reveals an arbitrary element while simultaneously exploiting a common perception by linking size value with sound value.

There would appear to be a contribution to the communication between conductor and musician from the level of intentionality; the structure of the signal from the baton must be deliberately constructed. In chapter two it was established that when two musicians are obliged to synchronise their actions without the aid of a conductor, the tracking and monitoring process becomes mutual. The critical events in the process of coordination must be targetted by an active process of prediction, rather than serving as triggers for previously timed actions. This was established in chapter four to follow from the achieved precision of timing and the absence of candidates for trigger events.

The means whereby information will be integrated into a musician's motor control will vary according to whether the situation requires re-organisation of the output of the control system (as, for example, at a change of tempo), or whether the situation requires a re-adjustment of the action pattern that takes its timing from the output of the control system (as would be necessary, for example, to remedy a perceived incipient error). A sufficient preview is required to allow smooth re-scaling of the metre, which, as discussed in chapter one, is the province of the control system. The metre-unit can be reset from the bar to the beat, or some fraction of the beat. In chapter three it was found that the bar was being used as the appropriate metrical unit to provide the overall coordination between two musicians. The length of the metre can also be reset, as in a change of tempo.

Input information could be used to recalibrate the programmable clock of the control system, resetting either starting point, or unit, or rate, or any of these. The timing features would then be represented in an abstract homorphic stochastic or ratio form, in an analogous way to that in which the conductor communicates variations required in output (for example, the grandeur) by varying the ratios of the component movement amplitudes, velocities, or timings. The array of ratios would form a series of targets to be negotiated by the motor system and would provide a continuous temporal reference. The discovery of a goal-directed phase in chapter four indicates that a shorter preview is required in a re-regulation at the level of the motor system of the movement trajectories geared with respect to the abstract timing representations of the control system.

It is proposed that the negotiation between the motor system and the control system of the musician in performance can be compared to that between the musician and the conductor described in chapter four, in that the conductor's baton indicates the "stepping stones" (a series of targets) which the player (or motor system) must negotiate. Just as the musician has a certain autonomy in deciding how best to achieve each target in the series, so the motor system must have a certain autonomy in the achieving of its temporal targets. The motor system itself acts as a timekeeper and actualises the internal timing of the coordinated series of movements.

We would present the development of musical skill as a process of achieving certain specified abilities. These fall into two categories.

(1) The first category concerns the smoothness and standard of coordination of the series of movements required to make a musical performance. This smoothness will be achieved by the following means.

(a) The development of an ability to more rapidly assimilate information and reconfigure, as necessary, the abstract features that represent the timing output at the level of the control system.

(b) The aquisition of a wider repertoire of features and action plans on which the control and motor systems can draw.

(c) The ability of the motor system to meet more rapidly any changes in timing demands that may be presented by the control system.

(d) The aquisition and automation of the process of formation of connections between action and event, as, for example, between a movement of the hand and finger and the action at the keyboard that produces the required sound at the right time. The formation of this connection commences as a simple association at the level of the motor system but enters the domain of the control system as the connection between action and event becomes increasingly abstracted.

(e) The development of a greater degree of overlap between the control system and the motor system while music is being made, the control system being able to formulate representations of future time series as the motor system accesses and actualises current demands, in parallel.

(f) The development of new relationships between the levels and the evolution of new biodynamic structures.

As every action takes place in a series of simultaneous and nested environments, the development of skill also involves:

(g) The maximization of integration with these environments. The increasing exploitation of system dynamics, peripheral forces, and biomechanical features, such as the potential to use the muscle synergy involved to generate rhythm, and physical features, such as the use of the weight and momentum of the arm and baton under gravity to communicate a series of temporal targets, are both involved in the aquisition of skills in a development towards the "greatest simplicity and economy of means".

(2) The second category concerns the development of the ability to express the psychological, interpersonal, and cultural meaning of the creating of the musical experience. This ability, which is partly in the psychological domain of intentionality, clearly has a determinitive effect on action. In chapter six it was shown that it is necessary to define the subject's goal before assessing accuracy of performance. Michon (1967) pointed out that interpretation could depend on variations on the times allotted to intervals. Thus musical skill is seen in the achieving of a derived time interval rather than a specified time interval. In chapter three it was pointed out that rubato (deviation from strict time) is often required to give expression to a musical phrase.

Chapter one reviewed the various models that have been proposed in the literature to account for serial ordering and timing of behaviour. Shaffer's model, which is best supported by the findings reported here, holds that there is a prior stage in the mapping of sequences onto an interval structure. This consists of the selection of the appropriate beat interval, which may be the bar, the beat, or some fraction of the beat. This selection may be influenced by a number of features, including the accent, tempo, and phrasing indicated, and the subject's experience, skill, and aesthetic sense. This model allows for rubato. The work by Shaffer and Sloboda, cited in chapter one, indicated that the derivation of real music (with expression) from the specified time intervals of the score is a reasonably lawful process, and it occurs at the time-scaling process stage. Expressiveness may entail varying volume, the use of legato, or variation of the IBI. Certainly, these are not simple responses triggered by the notation. It is a sophisticated and creative process, involving contributions from the various levels of the motor actualisation process, including that of intentionality.

The psychological dimension is also critical because the relationship between actions and their consequences is a dynamic dialogue. A perception is conditioned by the environmental ecology of the stimuli and opportunities for interaction on the one hand, and by selective attention and action based on current organismic needs and priorities on the other. The human environment includes cultural and interpersonal dimensions. For example, the temporal patterning of language is an intersubjective phenomenon, as is attribution of intent and awareness of motivation. The latter may involve a derivation of a person's intentions from observations of their actions, or to the level of planning from the level of programming.

Results by Marcus, also cited in chapter one, indicate that perceptual centres in speech are a property of the whole stimulus and reflect properties of both the production and perception of speech. Marcus argued that it is pointless to try to determine any single acoustic or articulatory correlate of centre location, or to attempt to determine a centre at a precise point in time. Similarly, it cannot be assumed that sound onsets or offsets are the elements of the strategy for timing in music.

The general conclusion that follows from the above discussion is that an understanding of musical performance must bridge all the domains; it must extend between that of motor actualisation on the one hand and the psychological and cultural context on the other. Thus a strictly reductive approach, which does not recognise the cultural context, must be inadaquate.

There are additional problems that arise with reductionism. In chapter five it was pointed out that if one studies relatively unskilled subjects in simple tasks one may not be able to make any valid extension of findings to explain skilled behaviour. The study of automation of linkage of action elements is not sufficient to explain the emergence of generative flexibility, timing fluency, and expressive improvisation. That is, the existence of more than one level in the model of motor coordination and the psychology of musical performance precludes simple reductive models, as explanation must invariably be on more than one level. Fluency in performance is achieved at the superordinate control level where movements are represented in an abstract form, possibly as intentions about end-states, and at the level of intentionality which includes considerations of overall strategy and sequencing of sequences of movements. Thus new principles of coordination arise in the development of skill. There is increasing transcendence to a superordinate level of timing control.

Methodologies and Models

The inadaquacy of a purely reductionist approach has implications for research methodology and for the scope of the models of behaviour. As for methodology, an adaquate procedure must involve the explanation of findings in the context in which the real behaviour occurs. A similar argument was advanced in chapter one to the effect that it is often necessary to study a range of real and complex behaviours in order to understand limited and simple instances. Accordingly, in chapters two, three, and four, the approach adopted was to reduce and control the parameters of information available to the musician in order to study the communication of information between conductors and musicians while ensuring that the situation remained within the bounds of real musicianship.

With regard to the construction of models, in chapter four it was stated that the need was to delineate an organising principle that remained relatively invariant over changing conditions within the range of normally occurring behaviour. The results in that chapter and in chapter six show that the invariance resides in the application of a principle, and not in an absolute form of behaviour. The results reported in chapter two demonstrated that while underlying forms may be quite clear, the situation is complex and multivariate, and deviations from the precise form may not be errors, but the expression of other intentional variables.

We are led to the conclusion that it is possible to evolve models of musical skills and the psychology of musical performance that have a certain general predictive validity. However, due to the partly indeterminate nature of the psychological and cultural domains, these models will inevitably be partial and approximate.

Conductors, for example, almost all agree on the need to give clear beats (McElheren (1966), Boult (1943)). Yet Furtwangler's baton trembled and twitched so much that his beats were not clear. This, however, contributed to the dynamism and vibrancy of his performances. Koussevitsky was also notorious for an indecipherable beat. Gibson has been accused of the same fault by one SNO player, in these words.

"his beat is indecipherable- he's a beatless conductor."

However, another SNO player has qualified this statement.

"It is all an attitude of mind- if you want to follow Gibson, he's perfectly easy to follow."

According to Borges and Sherman (1981), Reiner gave such a tiny beat that many players could not see it.

Thus there are exceptions to the clear beat rule, as there are to every musical rule. In a field of behaviour as complex as that of musical skills there are always such considerations as conscious adoption of strategies and meta-strategies. It is always necessary to assess what the musicians actually did in terms of what they were aiming to do. The situation is thus not entirely like other performance skills. A long jump, for example, is successful as a biomechanical event if the effort is brought to bear at just the right moment,in the right way,and the criterion of that success is that the athlete achieves the best distance of the day (Lee (1977)). The criterion in the case of music is not independent in this way. Critics may disagree forever as to the validity of an interpretation of a piece of music.

Thus in deciding what is being attempted in a performance it is necessary to think in terms of the aim of music as communication. This might reflect its design for a purpose, to create an emotional or aesthetic effect for example, or an attempt to express a universal or transcendent perception at a higher level. Any models of the operations of musical performance must ultimately be capable of integration into this broader context. They must be compatible with the experience of musicians and with other models of cooperative phenomena.

There is a precedent for this integrated approach to music. Smith (1979) points out that in Hellenic Greece, for example, it was believed that music spoke directly to human emotions and affairs, and that music in the major scale made men slack and sentimental, while music in the minor scale stiffened the nerves and sinews.

As a more contemporary example, there are parallels between the concept of teleology as implicate purpose and the structure of music. Purpose is not separate from events, as it would be understood in a dualistic system, but is and is expressed in the pattern of those events. Just so with music, which does not exist apart from notes or sounds, but is and is expressed in the pattern of those sounds. In both cases, the plan is not separate from the action, but is implicate within it.

Thus to study music solely in terms of notes, and to ignore the strategies that determine the structuring of those note, is parallel to studying psychology solely in terms of nerve cells. Oatley (1978) has pointed out that this is to beg the primary question of whether form follows function or vice-versa.

Smith discusses this problem in a review of the phenomenon of hearing. He concludes that we do not hear because we have ears, rather we evolved ears because we were potentially hearing beings. There is, naturally, a biological substrate. The phylogenetically antecedent organ to the ear is the lateral line of the fish, which is sensitive to vibration.

The general version of this statement is that if a suitable environmental information-bearing dimension exists, organisms may evolve to take preferential advantage. Thus in cave-dwelling fish that become blind, there is an allometric relationship between the representation of the lateral line and the visual cortex. This is essentially a realist position. If we add that the information-bearing dimension exists as a psychological reality and that this aspect of it is therefore created by the consciousness of the organism, then we have an ecological wholism. Smith adds that different creatures have different ears and that one can describe ears and the frequencies impinging upon them without understanding the existential reality of what it is to hear a sound which has meaning. A sound has meaning within the context of a creature in an environment, rather than in the precise physical nature of the stimulus. For a more complete understanding, it is necessary to comprehend all these levels that together constitute the actual phenomenon. Thus in the performance of music there are considerations of the process of motor coordination and actualisation of intent involved, in a context of immediate and evolving internal and external timing demands, which itself is in a context of music which may be an expression of any of the possibilities discussed in chapter one, including breathing, language, thought processes, interpersonal communication on a multiplicity of levels, emotion, creativity, or the organising power of life, or any or all of these.

The methodological problem reviewed here, the author believes, is an instance of a current paradigm shift in science and culture. Waddington (1972, 1977), Toynbee (1972), and Capra (1982) have argued that the underlying change is profound and extensive. Ehrenfeld (1978) has argued that the direction of change is away from homocentrism or humanist philosophies.

Historical Background to Contemporary Homocentrism in Psychology

Homocentrism is associated with a scientific methodology evolved with principal contributions from Descartes, Bacon, and Newton. This methodology rests on concepts such as determinism, reductionism, dualism, and objectivity. The methodology was extensively adopted and influenced philosophies. Marx (in Bender, 1972, and Tucker, 1972) has described the principles of such influence.

Homocentrism has had certain political as well as philosophical and methodological consequences. For example, the consequences of the perceived separation of the human, moral, and physical domains have been profoundly destructive, both to the human psyche and to the natural environment. This process has been examined by Martin (1982) and Freedman (1960) amongst others.

Biology and psychology have been extensively influenced by reductionism and mechanistic concepts. Descartes argued that there are two realms of reality, parallel but distinct, each of which could be studied without reference to the other. Consciousness was entirely in the domain of the mind-soul, and acted on the body via the pineal gland. This gland impelled animal spirits, via the pores of the brain, into the nerves, there to alter (hydrodynamically) the shape of the muscles in which the selected nerves terminated. Thus the adoption of the Descartian distinction between the Res Cogitans and the Res Extensa created the conceptual problem of how mind and brain or body interact with each other. The very close parallel between the Cartesian formulation and contemporary neurophysiology, which illustrates the continuing influence of reductionism and mechanism, has been observed by Lashley (1950) in the following words.

> "Descartes theory (of brain mechanism and functioning) has a remarkably modern sound. Substitute "nerve impulse" for "animal spirits", "synapse" for "pore"."

The alternative viewpoint in Descartes' day was represented by Leibniz and Spinoza. Leibniz argued for a pre-established harmony, Spinoza for monism; the view that there is only one kind of ultimate substance or reality.

However, the Cartesian model was widely adopted. Hobbes and Locke took a more extreme view than Descartes. They refuted Descartes' concept of innate ideas and maintained, in Locke's phrase, that we were born tabula rasa. This was the basis for the extreme empiricist position in the mechanistic theory of knowledge, in which sensations are the basic elements which are combined into more complex structures by the process of association.

The combination of the concept of association with that of the neurological reflex by Hartley (in Priestley (1790)) formed the basis of the claim, first articulated by Sechenov and Pavlov (1927), that eventually all human behaviour could be understood in terms of combinations of reflex mechanisms. The strong statement of the theory of psychophysics (an elementalist position), which originated with Weber, Fechner, and Helmholz (in Warren and Warren, 1968), makes a similar claim for perceptual processes.

It is additional evidence for the need for a scientific revolution that now, as Oatley points out, the concept of the reflex can no longer be considered explanatory, given that it must be substantially modified to meet the experimental evidence provided by

Lashley (1949, 1950).

The theories of the nineteenth century experimental psychologists were reductionist, dualistic, and materialistic. For example, both structuralist and behaviourist schools incorporated the basic concepts of Newtonian mechanics: structuralists tried to analyse consciousness into its basic elements and behaviourists attempted to isolate cause and effect relationships between units of behaviour. Alternative views were represented by gestalt psychology and functionalism, which emphasised the unitary nature of consciousness and perception. The essential idea of the Gestalten is that of meaningful organisation and structuring of the sensory information. Functionalism, according to Darwin (in Bates and Humphrey, 1957), meant understanding each anatomical structure as a functioning component of an integrated living organism engaged in the processes of evolution and survival. This is an emphasis on dynamic processes, rather than on static structures, and on their functioning in relation to the mode of existence of the organism. This is an early statement of the need for ecologically valid explanations. James (1890, in Burkhardt, 1981), a prominent exponent of functionalism, argued that concepts of elements of mental function and rules for the association of ideas were, in fact, imposed cross-sections of a continuous process that had to be understood in terms of a constant organism-environment interaction.

The experimentalist approach remained dominant, however, being adopted by Watson (1914) into behaviourism and Titchener (1915) into structuralism. A particularly critical addition at this time was Loeb's theory of tropism, which Loeb explained in terms of forced movements imposed on the organism by environmental inputs in a strictly mechanistic fashion. Behaviourists such as Bekhterev (1933) developed similar theories of the learning process as consisting of the compounding of simple conditioned responses. Watson attempted to extend this theory to include all human experience, denying any need to include any concept of consciousness. He stated that psychology

> "needs consciousness as little as do the sciences of chemistry and physics."

Capra points out the irony of this statement, given Wigner's (in Capra (1975)) claim that

> "It was not possible to formulate the laws of (quantum theory) in a fully consistent way without reference to consciousness."

The application of behaviourist theory to the learning process, with explanation couched in terms of conditioning, required an emphasis on experimental and situational control that is in the true Baconian tradition. The Skinnerian (1971, 1972) concept of operant behaviour is more sophisticated than classical behaviorist theory, but is still mechanistic and reductionist in the Newtonian sense. Thus organisms are still seen, as Weiss (1971) puts it, as

> "puppets operated by environmental strings."

There is no attempt to assess the mutual interplay between organism and environment, or the sense in which organism and environment are mutually defining and necessary, that is, themselves form a larger organic ecology.

The Alternative Ecological Philosophy

The alternative to a homocentric philosophy I shall refer to as ecological philosophy. Developments in physics, psychology, and other areas have contributed to the transition between these philosophies.

In the field of physics the seminal work was published by Einstein in 1905 (Einstein and Infeld, 1971, and Schilpp, 1949). Many others, notably Heisenberg (1952, 1958, 1959), Einstein, Podolsky, and Rosen (1935), Bohr (1934), Bell (1964, in Stapp, 1979), Compton (1923, in Zukav, 1979), de Broglie (1964), and Jeans (1930), have all contributed to the development of theories of quantum dynamics and relativity.

These theories indicate that the basic stuff of reality is not matter, nor yet energy, but information. Interactions are more fundamental than objects. The universe is a web of interactions which are instantaneously interconnected. Humans are components in, and not apart from, this process. Observations of reality are interactions with it and affect it. Thus the classical definition of objectivity cannot be maintained. This does not mean (as Husserl (1900) argued) that reality can be equated with consciousness, but that mind and matter are ultimately manifestations of the same system.

This world view is systemic and interconnected, and may thus be termed ecological.

Birch and Cobb (1981) have developed ideas by Bateson (1972) and Whitehead (1926, 1929) to explore the implications of this world view. They argue that it requires a concept of implicate purpose, similar to that presented earlier for a model of music. They have applied this concept to the theory of evolution as a third variable to Monod's (1971) chance and necessity. Unlike Lamarckism and Darwinian theories, which both see the organism as a respondent to alterations in the environment (in Gould, 1978a, 1978b, 1981), Birch and Cobb see the organism as actively engaged in evolving. Evidence for this has been provided by Lovelock (1979).

The general ecological approach pictures the organism as inseparably interconnected with its environment. The mechanistic approach defines entities or substances as having some measure of independent existence. Relations between entities so conceived are referred to as external relations. Entities are thought of as existing independently of their relations, before they enter into them. External relations are not, therefore, considered to be consitutive or necessary aspects of the entity's existence. The ecological model, in direct contrast, states that the relations of the entity are internal, that is, constitutive or necessary aspects of its character or existence. In fact, Birch and Cobb argue, existence means relations.

If the concept of the "substance" of entities is defined in terms of independent existence, and if this is accepted as inadaquate, then the internal relations referred to can only be constitutive of events, or processes, and not substances or things. Thus the shift from a mechanistic to an ecological approach requires a shift from substance to event thinking. The following quotation from Birch and Cobb makes this quite clear.

> "Even when one thinks of an event one is still too likely to bring from substantialist habits of mind the notion of something self-contained and self-sufficient. If so, one will have failed to attend sufficiently to the evidence, whether from physics or biology. An electromagnetic event, for example, cannot be viewed as taking place independently of the electromagnetic field as a whole. It both participates in constituting that field as the environment for all the events and also is constituted by its participation in that field. In abstraction from that field it is nothing at all. It does not have independent existence and then relate to the field. It is constituted by the complex interconnections which its place in the field gives to it. The same is true when the event in question is the functioning of a gene, a cell, or a rabbit. This functioning does not exist in itself apart from its total environment and then relate to the environment. It is a mode of interacting, of being affected and affecting."

Thus "things" are actually enduring "societies of events", with the stability residing in the pattern of flux rather than in substance.

<u>Homocentric and Ecological Approaches in the Psychology of Action</u>

Work in the field of perceptual psychology has centred around the need to explain how a homunculus in the head could extrapolate accurately the state of affairs in the world beyond the confines of the cranium. Work by such researchers as Ames (in Ittelson, 1968) or Gregory (1966) is in this dualist tradition.

However, when one starts to question the existence of the homunculus, this changes the nature of the theoretical question.

When Gibson (1979) rephrased the problem of visual perception in terms of available information-bearing arrays, it became possible that the homunculus might not exist. If the necessary visual information was ever present in the optic array, and available in a way that was invariably structured by, and hence with reference to, the organism's physical dimensions, then the process of visual learning necessitated by the existence of the homunculus would not be necessary.

Secondly, with the development of the idea of information-bearing arrays into flow-field theory by Lee and Lishman (1974), and Lee (1976, 1978), came the possibility that time was an integral factor in the process of perception and not a second-order derivation or adjunct. That is, variables that we term speed and acceleration might be directly available in the visual flow in terms of time-to-arrival at a given point.

Thirdly, both possibilities in conjunction point to a general theory of perception that is in essence more parsimonious than the empiricist hypothesis. That is, as we evolved on and of this planet, so it seems likely that we should be innately equipped to perceive it the way it is, in terms of dimensions that have relevance to us. This was developed by Gibson into the theory of affordances. An affordance is an invariant description of some aspect of an organism's environment, given with respect to the organism's physical scale and potential.

This is, then, a synergistic theory of perception and as such can be fairly termed ecological, as all interactive relationships in a given ecology are at some level synergistic.

A similar analysis obtains in the field of action timing. Any theory of action timing must be able to explain very complex timing, such as is involved in playing music and coordinating the action timing with other people. There have been many models evolved in attempts to explain how these rhythms are heard and produced; from Deutsch (1973, 1975) Michon (1967), Wing (1977, Wing and Kristofferson, (1973), and others, some of them very sophisticated. Many, including the forementioned, make the reductionist assumption that apparently complex rhythmic output must result from the coupling of simple rhythmic unit generators. These models then tend to become over elaborate as they seek to explain how that we are able to produce such a large range of types and complexities of rhythms.

An alternative analysis supported by Turvey et al (1978), Kelso and Holt (1980), and Kelso et al (1981), is based on the fact, first described by Von Holst (1937) that muscle synergies manifest many of the properties of limit cycle oscillators. That is, the output is inherently rhythmic. By driving such a system at different speeds, a range of rhythms may be produced, and by restructuring the muscle synergistic grouping, a new range may be introduced.

Bernstein (1967) proposed that movements are created and maintained by the "biodynamic structures" of body and brain. He demonstrated that the form of locomotion was a resultant of cyclical forces in muscles, under command of the central nervous system, and reactive forces arising periphally from the inertia of the body parts under gravity.

Musical rhythm, we should note, is similar to muscle output rhythm in that it is not isochronic, but refers rather to the preservation of a regular form throughout a series of perturbations or (in musical terms) variations.

If the system possesses many of the properties we wish to investigate, and therefore does not have to have these functions "imposed" on it by the will, we avoid both reductionism and dualism. This more ecological theory of perception is based primarily on a consideration of the existing system parameters defined with respect to the organism.

Trevarthen (in Olson (1980)) extends this idea further, to argue that we are innately social and communicating beings in a way which is similar to Chomsky's (1980) argument for innate language capabilities, or the suggestion from Baily (1977), Baily and Blacking (1978), and Blacking (1983) that musicality is innate.

The Psychodynamic View of the Mind, and Interpersonal Psychology

In psychoanalysis a parallel series of developments occurred. Freud's theories describe a mutually inhibiting dynamic balance between psychological structures, and there is an emphasis on the relation between internal and external reality, especially in the way a patient's internal state affects social perceptions and in the way in which an input from the analyst can affect a given internal balance. The theory is thus more dynamic and interactionist than classical behaviourism, which described learning in static and linear terms. However, Freud's belief was that ultimate explanations would be in terms of physics. In 'Psychoanalysis and Telepathy' (1921) he said

> "Instead of waiting for the moment when (analysts) will be able to escape from the constraint of the familiar laws of physics and chemistry, they hope for the emergence of more extensive and deeper-reaching natural laws, to which they are ready to submit."

Thus he attempted to shape his theory in physicalist terms. The physics of Freud's day was Newtonian, and Freud's theories are couched in terms of Newtonian mechanics and a psychological equivalent of absolute Euclidean space.

Thus the structure of the conscious-unconscious is given in topographic terms, the unconscious lying beneath the conscious. The id, ego, and superego have distinct object identities, in that they cannot occupy the same psychological space. These constructions are defined in terms of extension, position, and motion. Similarly, the Freudian concepts of drives and defences parallel the Newtonian concepts of action and reaction.

Freud's wish to ground his theory of knowledge led to his adoption of a mechanistic model. Jung's argument with Freud for a transcendence of the limits of the rationalistic approach parallels those later developments in physics that demonstrated the limits of applicability of Newtonian mechanics.

Jung (1928) described the psyche as a self-regulating dynamic system which had to be understood in its totality and in relation to the wider environment. He argued that even the defined boundaries of the psyche must be extended, in these words.

> "We would probably do best to regard the psychic process simply as a life-process. In this was we enlarge the narrower concept of psychic energy to a broader one of life energy, which includes 'psychic energy' as a specific part. We thus gain the advantage of being able to follow quantitative relations beyond the narrow confines of the psychic into the sphere of biological functions in general.."

Later (1951) he argued for a further extension, even into the realm of matter.

> "Sooner or later, nuclear physics and the psychology of the unconscious will draw closer together as both of them, independently of each other and from opposite directions, push foreward into transcendental territory..psyche cannot be totally different from matter, for how otherwise could it move matter? And matter cannot be alien to psyche, for how else could matter produce psyche? Psyche and matter exist in the same world, and each partakes of the other, otherwise any reciprocal action would be impossible. If research could only advance far enough, therefore, we should arrive at an ultimate agreement between physical and psychological concepts."

This was, in effect, a statement of the dissolution of the concepts of objectivity and of the independent status of the observer. The Jungian concept of the archetypes of the collective unconscious has implicit in it a notion of a fundamental interconnectedness between the individual and humanity as a whole.

Similarly, in his methodology, Jung emphasised that the rational approach was but one of several possible approaches, each of which would result in a distinct description of reality. This is a systems theory. The concept of synchronicity, which Jung introduced to connect acausal but meaningfully ordered events, closely parallels the notion of ordered connectedness which has been found useful in analysis of the difference between causal or local connections and acausal or non-local connections in particle physics.

The humanistic psychology of Maslow (1962), Assagioli (1965), Rogers (1951,1970), and Grof (1976) emphasises that humans should be studied as integral organisms, with innate potential to perceive and communicate. This may be contrasted with the dissociation of reactions, believed to be behavioural units, in the behaviourist model.

Sullivan (1953) also concentrated on the interpersonal, stating that the human organism could only be understood in the context of the network of human relations in which it exists. The common theme of these contributions is the notion of integration. Thus the conceptual basis of psychology must be consistent with biology on the one hand, and be capable of expansion to include the emotional, social, cultural, and spiritual environment on the other.

There is an tacit question here as to the extent to which scientific psychology can be capable of this expansion. Is it possible to make scientific statements about consciousness? If consiousness is central to psychology, can psychology be regarded as a science? This depends on the definition of science. The science of Galileo is concerned with quantitative statements and is inherently incapable of dealing with consciousness. It is necessary, therefore, to adopt an expanded definition of science.

Ecological Science, Systems Theory, and an Appropriate Methodology

If the objectivity of the observer is relative, rather than absolute, then it follows that categorization of phenomena is essentially a subjective or psychological process rather than an existent one.

The general definition of scientific procedure that emerges from a fundamental ecological perspective is this. All scientific theories are approximations to the true nature of reality. Levels of reality are not reducible to each other, therefore each theory may be valid for a certain range of phenomena. Beyond this range the theory no longer gives a satisfactory description. It must then be either replaced or extended to give an improved approximation, or integrated with other partially successful models, each with a defined and limited domain of applicability. Science is then a process of construction of a sequence of limited and approximate models, each, by virtue of a quasi-Popperian (1963) critique, may be more accurate than the previous,but none will represent a complete and final account of natural phenomena. If matter is a structured flux of energy, and particles are events or connections rather than "things", then no type or series of particles can be said to be fundamental to any other. Furthermore, the properties of particles seem to be determined, in some sense, by the process of observation. Thus it may be a mistake to attempt to construct theories which purport to explain reality at a more fundamental level than others, firstly because the construction of a theoretical hierarchy may not reflect the operations of reality, and secondly because observed patterns of matter are in part reflections of patterns of mind and hence susceptible to modelling by our theories.

Thus the critique is achieved by checking models for self consistency and compatibility with existing models, rather than by seeking to replace models outright by more fundamental models. Tyrrell (1930) gives the following illustration.

> "Take a book, for example. To an animal a book is merely a coloured shape. Any higher significance a book may hold lies above the level of its thought. And the book is a coloured shape; the animal is not wrong. To go a step higher, an uneducated savage may regard a book as a series of marks on paper. This is the book as seen on a higher level of significance than the animal's, and one which corresponds to the savage's level of thought. Again it is not wrong, only the book can mean more. It may mean a series of letters arranged according to certain rules. This is the book on a higher level of significance than the savage's...Or finally, on a still higher level, the book may be an expression of meaning..."

Schumacher (1977) argued that in all these cases the sensory data are the same. Only the observer determines the level of significance. This is only true in an abstract sense. As Haldane (1927, 1941) pointed out, a sensory perception is a function of the object-organism interaction. This is similar to Gibson's concept of the affordance, but Haldane placed greater emphasis on the value of pre-existent mental structures and attentional focus in selecting data. At other, non-visible levels, we further understand that the book is made of molecules, atoms, or a shaped flux of energy. All these are true, and the models appropriate to each level should not be regarded as subsuming each other, but complementing each other. Berlinski (1976) has argued that the attempt to replicate human reasoning in artificial intelligence is a misconstruing of the level of reality that is to be modelled.

The general metaphysic has been termed "systems theory" or, in its application in physics, "bootstrap theory" (Chew, 1961). Pasteur provided a clear exposition of the method.

> "Science advances through tentative answers to a series of more and more subtle questions which reach deeper and deeper into the essence of natural phenomena" (in Dubos, 1968).

If it is accepted that no single paradigm, including the Newtonian-Cartesian paradigm, is adaquate, what are the implications for research methodologies in the social sciences? The idea that time-, context-, and value-free statements are possible is based on the concept of objectivity. If this cannot be maintained, then how can we achieve rigourous and reliable results? The answer is given by the general application of systems theory. The key notion is that of congruence. Thus, instead of demanding results that are proof against contamination from masking or competing factors, we ask instead that the results be believable (congruence with prior theories). Instead of results being proof against situational factors, we ask that results be context-relevant and inter-context transferable (congruence with current theories concerning the same or related areas). Instead of strict replicateability we require that the data be dependable or stable (congruence of data patterns over replications). Finally, instead of assuming the possibility of objectivity, we ask that the pattern of results be confirmable by others.

Lincoln (1981) and Smith (1983) note that in social science we do not have equal status laws and data with those that have accrued in the natural sciences. Lincoln concludes that this is because natural science models are inappropriate for the social sciences, as we cannot achieve equivalent "randomness" (see also the note on small-sample statistics in the review of the methodology in chapter one). There are, of course, some generally accepted axioms, but as these are not strictly demonstrable, the criterion for axiom selection or retention is not that it should appear logical but that there should be a good fit between the various axioms, and between the axioms and the phenomena. As Jung (1960) states, a scientific hypothesis is never proved absolutely insofar as the possibility of an improvement always exists. The only proof is its applicability.

In a parallel development to the way in which we are led to reject the concept of relative fundamentalism of theories, Lincoln argues that there is no inherent reason why one set of methods is better than another. This does not mean that each researcher must start afresh, only that we should select from the available range of qualitative and quantitative methods available to us those that give the best verstehn (understanding, feel for the subject). This is similar to Cronbach's (1954) idea of constant reformulation of working hypotheses.

It may be that a single precise and unified ecologically valid methodology is impracticable, and that we must operate with a mosaic of interlocking methodologies, guided by general principles.

Capra suggests that the definitions of a scientific enquiry should be as follows:
First, that knowledge must be based on systematic observation (the empirical basis).
Second, that knowledge must be expressed in terms of self-consistent, but limited and approximate models (model making). Quantification per se may be useful, but is not a part of the primary definition of science.

Phenomenologists, such as Smith (1979), concentrate on the immediate experience of an event. This, they argue, must precede effective and useful categorisation. The general approach can be stated simply. Avoid precategorisation and allow the phenomena to "resolve themselves" into natural components. This approach is, of course, based on an appeal to what Polanyi (1958, 1969), and Polanyi and Prosch (1975) called tacit or personal knowledge.

Personal knowledge, according to Polanyi, is contact with reality, and an answer to the philosophical problem of the meaning of knowing. It is based on personal experience of the self and the universe formed during the lifetime and development of the individual, and the evolution of the species. It is, in turn, based on the realist position which states that it would be counter-evolutionary should life-forms evolve without means of appropriate but essentially veridical perception of the environment.

Thus the phenomenologists' appeal to intuition is related to the Gibsonian proposal for a motoric, body-scaled comprehension of the world. The difference is one of emphasis. Where Gibson concentrated on innate structure, akoumenologists like Smith allow a role for empirical experience in shaping and refining perception-still, however, within existent or "natural" structures.

Ecological Metaphysics and Theology

Darwin achieved as profound an impact in biology and related sciences as quantum theoreticians did in physics. The theory of evolution, and the subsequent disclosure of our origins, undermined the separation between human and other organisms that was central to homocentric philosophies. Darwin also questioned the idea that development was towards a particular goal. He believed that development was simply towards a more favorable adaption to changes in the environment. He also insisted on the fundamental role of chance in providing mutations as the raw material for the process of selection.

Thus, although the impact of Darwin's main thesis is to further undermine homocentrism, it is in some ways also a materialist position. It is a materialist position because of this fundamental role of chance. However, the notion of truly random chance must now be called into question, firstly as an inability to summate all the influences in a particular interaction does not mean that the undefined element represents chance, but rather that it represents non-local or uncontrolled effects, and secondly if we adopt Birch and Cobb's concept of the implicate purpose of the organism engaged in the process of evolution.

There is a compatible position, argued by Skolimowski (1981). He suggests that we may be forced by the logic of our position to end up with a theology. We know that the universe is a flux of energy. It is a highly structured flux, as our presence here attests. There are, then, organising principles or themes, of which particles are one and human consciousness another manifestation. Skolimowski refers to the organising principle as life. This is similar to Pantheism or Taoism. This is essentially the vision of God described by Spinoza in his 'Ethics' (first published in 1677), and in his 'Tractatus'. Spinoza offers a sound grounding for theories of veridical perception. Knowledge, according to Spinoza, is a principle that at once transcends and explains all the differences of the finite world, and is determined by the whole. Knowledge, just as does the process of evolution, proceeds from unity and differentiates. This theological position would see the process of evolution as not operating randomly, nor by deliberate design (because that would require the existence of an antecedent design, separate from the process, whereas in this vision, God is seen as immanent; in fact, as constituting the process) but as the unfolding of a theme.

Quite what the climax to this theme might be is the proper subject of theology, but it is certainly interesting to speculate that the transition from homocentric to ecological philosophies may further evolve into a reconciliation of science and religion, and an intellectually satisfying and rationally based theology.

Conclusions

The programme of research revealed the necessity to adopt a multivariate analysis on a multiplicity of interacting levels. This demonstrated the inadaquacy of a reductive approach, and the necessity to adopt a more ecological philosophy. This philosophy is supported by the evidence presented in psychology and in other disciplines, and has profound implications for methodology, science, and culture.

Appendix one

References

Aiba, T.S.
Some aspects of motion perception: An analysis by predictive judgement
Ann.Rep.Cult.Sci., Hokkaido University, Fac.of Let., 1977, 26, 3-28

Allen, G.D.
The place of rhythm in a theory of language
UCLA working papers, 1968, 10, 60-84

Allen, G.D.
The location of rhythmic stress beats in English. Parts I and II.
Lang.and Speech, 1972, 15, 72-100 and 179-195

Assagioli, R.
Psychosynthesis
N.Y. Viking, 1965

Baily, J.S.
Movement patterns in playing the Herati Dutar
in J.Blacking(Ed.), The Anthropology of the Body, ASAC Conference report
Queen's Univ., Belfast, 1977

Baily, J.S., and Blacking, J.A.R.
Research on the Herati Dutar
Current Anthropology, 19(3), 1978, 610-11

Baker, R., and Nelder, J.
The GLIM System, Release 3
Oxford: Numerical Algorithms Group, 1978

Barnsley, R.H., and Rabinovitch, S.
Handedness: proficiency versus stated preference
Percept.and Mot.Skills, 1970, 30, 343-62

Bartlett, N.R., and MacLeod, S.
Human reaction time
J.Opt.Soc.Amer., 1954, 44, 306-311 and 374-379

Bartlett, N.R., and Bartlett, S.C.
Synchronization of a motor response with an anticipated sensory event
Psych.Rev., 1959, 66(4), 203-218

Bates, M., and Humphrey, P.S.
The Darwin Reader
London, 1957

Bateson, G.
Steps to an Ecology of Mind
N.Y., Ballantine, 1972

Beaton, A.A.

Hemisphere function and dual task performance
Neuropsychologica,1979,17,629-35

Bekhterev,V.A.
General Principles of Human Reflexology.An introduction to the objective study of personality
E.and W.Murphy(Tr.4th ed.),London,1933

Berlinski,D.
On Systems
Boston,Mass,MIT Press,1976

Bernstein,N.A.
The Coordination and Regulation of Movements
Pergamon Press,1967

Birch,C.,and Cobb,J.
The Liberation of Life
C.U.P.,1981

Blacking,J.
How Musical is Man ?
Faber and Faber,1973

Blacking,J.
Dance and music in Venda children's cognitive development
research seminar,Edinburgh,1983

Bohm,D.
Wholeness and the Implicate Order
London,Routledge and Kegan Paul,1980

Bohr,N.
Atomic Theory and the Description of Nature
C.U.P.,1934

Boneau,C.A.
The effects of violating of assumptions underlying the t-test
Psych.Bull.,1960,57,49-64

Borges,V.,and Sherman,R.
Borges Musical Briefs
Methuen,1981

Boult,Sir A.C.
Thoughts on Conducting
London,1963

Boult,Sir A.C.
A Handbook on the Technique of Conducting
Hall Oxford,1943

Broglie,L.de
The Current Interpretation of Wave Mechanics;a Critical Study
Amsterdam,1964

Brown,J.S.,and Slater-Hammel,A.T.
Discrete movements in the horizontal plane as a function of their length and direction
J.Exp.Psych.,1949,39,84-96

Capra,F.
The Tao of Physics

Berkely,Shambhala,1975

Capra,F.
The Turning Point.Science,Society, and the Rising Culture
Wildwood House,1982

Carlton,L.G.,Carlton,M.J.,and Newell,K.M.
Timing fast and slow constant velocity movements
Human Movement Science,1983,2,1-13

Chase,R.,Rapin,I.,Gilden,L.,Sutton,S.,and Guilfoyle,G.
Studies on sensory feedback II
Sensory feedback influences on keytapping motor tasks
Quart.J.Exp.Psych.,1961,13,153-167

Chernikoff,R.,and Taylor,F.V.
Reaction time to kinesthetic stimulation resulting from sudden arm displacement
Jour.Exp.Psych.,1952,43,1-8

Chew,G.F.
S-Matrix theory of strong interactions,etc.
Frontiers in Physics,N.Y.,1961

Chomsky,A.N.
Syntactic Structures
The Hague,Netherlands:Morton,1957

Chomsky,A.N.
Rules and Representations
Oxford,1980

Cooke,J.D.
The organisation of simple skilled movements
In G.E.Stelmach and J.Requin(Eds.)
Tutorials in Motor Behaviour
Amsterdam:North-Holland,1980

Craik,K.J.W.
Theory of the human operator in control systems II Man as an element in a control system
Brit.J.Psych.,1947,38,142-148

Cronbach,L.J.
Educational Psychology
N.Y.,1954

Darnton,C.
You and Music
Pelican,1940

Deutsch,D.
Octave generalization of specific interference effects in memory for tonal pitch
Perc.and Psych.,1973,13,271-275

Deutsch,D.
Musical illusions
Sci.Amer.,1975,233,92-104

Dixon,N.F.,and Spitz,L.
The detection of auditory visual desynchrony

Perception,1980,9,719-721
Downie,N.M.,and Heath,R.W.
Basic Statistical Methods
N.Y.,Harper and Row,1959
Dresslar,F.B.
Some influences which affect the
rapidity of voluntary movements
Amer.J.Psych.,1892,4,514-527
Dubos,R.
Man,Medicine,and Environment
N.Y.,Praeger,1968
Dukes,W.F.
N=1
Psych.Bull.,1965,64,74-79
Duncan,J.
Divided attention:the whole is
greater than the sum of its parts
J.Exp.Psych.:Human perception
and performance,1979,5,216-28
Dunlap,K.
Reactions to rhythmic stimuli,
with attempts to synchronise
Psych.Rev.,1910,17,399-416
Edgington,E.S.
Statistical Inference from N=1 Experiments
J.Psych.,1967,65,195-199
Efron,R.
The effect of handedness on the
perception of simultaneity and
temporal order
Brain,1963,86,261-284
Ehrenfeld,D.
The Arrogance of Humanism
O.U.P.,1978
Einstein,A.and Infeld,L.
The Evolution of Physics
Cambridge,C.U.P.,1971
Einstein,A.,Podolsky,B.,and Rosen,N.
"Can Quantum-Mechanical Description of
Physical Reality be considered Complete?
Physical Review,1935,47,777
Elkind,J.I.
Characteristics of simple
manual control systems
MIT Lincoln Laboratory,Tech.Rept.III,
Lexington,Mass,1956
Estes,W.K.
An associative basis for coding
and organisation in memory
In A.W.Melton and E.Martin(Eds.)
Coding Processes in human memory
N.Y.Halstead,1972
Falkenberg,L.E.,and Newell,K.M.

The relative contribution of movement time,amplitude,and velocity on response initiation
J.Exp.Psych.:
Human Percept.and Perf.,1980,6,760-768

Fel'dman,A.G.
Superposition of motor program.I.
Rhythmic forearm movements in man
Neuroscience,1980,5,81-90

Festinger,L.
The significance of difference between means without reference to the frequency distribution function
Psychometrika,1946,11,97

Fitch,H.,and Turvey,M.T.
On the control of activity:
an ecological point of view
In Landers and Christina (Eds.)
Psychology of Motor Behaviour and Sport,1977

Fitts,P.M.
Engineering psychology and equipment design
In S.S.Stevens (Ed.)
Handbook of experimental psychology
N.Y.,Wiley,1951,Pp.1287-1340

Fournie
Essai de Psychologie
Paris,1887

Fowler,C.A.
Timing control in speech production
Ph.D.Thesis,University of Connecticut,1977

Fowler,C.A.
"Perceptual Centres" in speech production and perception
Perception and Psychophysics,1979,25,375-88

Fraisse,P.
Contribution a l'etude du rhythme en tant que forme temporelle
Journal de psychologie normal et pathologique,1946,39,283-304

Fraisse,P.
Les structures rhythmiques
Louvrain:Publications Universitaires de Louvrain,1956

Fraisse,P.
The Psychology of Time
London,Eyre and Spottiswoode,1964

Fraisse,P.,and Voillaume,C.
Les reperes du subject dans la synchronisation et dans la pseudo-synchronisation
Annee Pschologique,1971,71,359-69

Fraisse,P.

Cues in sensory-motor synchronisation
In L.Schering,F.Halberg,and J.Pauli (Eds.)
Chronobiology
Tokyo,Igaku Shoin Ltd,1974,Pp 517-522

Freedman,P.
Principles of Scientific Research
2nd Edition.Oxford,1960

Freud,S.
'Psychoanalysis and Telepathy'(1921)
In J.Strachey(Ed.) Standard Edition
of the Complete Works of Sigmund Freud
Vol 18,N.Y.,Hogarth,1955

Gattey,C.N.
Peacocks on the Podium
Hutchinson,1982

Gelfand,I.M.,Gurfinkel,V.S.,Tsetlin,M.L.,and Shik,M.L.
Some problems in the analysis
of movements
In I.M.Gelfand,V.S.Gurfinkel,S.V.Fomin,
and M.L.Tsetlin (Eds.)
Models of the structural-functional
organisation of certain biological systems
Cambridge:MIT Press,1971

Gentile,J.R.,Roden,A.H.,and Klein,R.D.
An Analysis-of-variance model for the
intrasubject replication design.
J.App.Beh.Anal.,1962,5,193-198

Gerard,R.W.
The biological basis of imagination;with
biographical sketch
Scient.Month.,1946,62,477-99

Gibson,J.J.
The Senses Considered as Perceptual Systems
Boston:Houghton Mifflin,1966

Gibson,J.J.
The Ecological Approach to Visual Perception
Boston,Houghton Mifflin,1979

Goldstone,S.,and Goldfarb,J.L.
Direct comparison of auditory and visual
durations
J.Exp.Psych.,1964,67,483-485

Gould,S.J. (a)
Ever Since Darwin;reflections
in natural history
London,1978

Gould,S.J. (b)
Ontogeny and Phylogeny
Cambridge,Mass,1978

Gould,S.J.
The Mismeasure of Man
N.Y.,1981

Green,
Temporal auditory acuity

Psych.Rev.,1971,78(6),540-551

Greene,J.,and D'Oliveira,M.
Learning to use statistical tests
in psychology
Milton Keynes,O.U.Press,1982

Greene,P.H.
Problems of organisation of
motor systems
In R.Rosen and F.Snell(Eds.)
Progress in theoretical biology
Vol 2,N.Y.,Acad.Press,1972

Gregory,R.L.
Eye and Brain:the Psychology of Seeing
W.U.L.,Weidenfeld and Nicholson,London,1966

Grof,S.
Realms of the Human Unconsious
N.Y.,Dutton,1976

Haldane,J.B.S.
Possible Worlds,and other essays
London,1927

Haldane,J.B.S.
Science of Everyday Life
London,Pelican,1941

Halliday,A.M.,and Mingay,R.
On the resolution of small time
intervals and the effect of conduction
delays on the judgement of simultaneity
Quart.J.Exp.Psych.,1964,16(1),35-46

Hartmann,D.P.
Forcing square pegs into round holes:
some comments on "an analysis-of-variance
for the intrasubject replication design"
J.App.Beh.Anal.,1974,7,635-638

Hartson,L.D.
Contrasting approaches to the
analysis of skilled movements
J.Gen.Psych.,1939,20,263-293

Hauty,G.T.
The effects of drugs upon the
components of hand steadiness
USAF Sch.Aviat.Med.Proj.Rep.,1954,
Proj.No.21-1601-004,Rep.No.5

Henderson,M.T.
Rhythmic organisation in artistic
piano performance
Univ.Iowa Stud.Psych.Music,1936,4,281-305

Heisenberg,W.
Philosophic problems of nuclear science:
eight lectures
F.C.Hayes(Tr.),London,1952

Heisenberg,W.
The physicist's conception of nature
A.J.Pomerans(Tr.),London,1958

Heisenberg,W.
Physics and Philosophy;the revelation in modern science
Gifford Lectures,St.Andrews University,1955-6
In World Perspectives,15,London,1959

Herrigel,E.
Zen in the Art of Archery
N.Y.,Random,1971

Hirsch,I.J.,Bilger,R.C.,and Deatherage,B.H.
The effect of auditory and visual background on apparent duration
Amer.J.Psych.,1956,69,561-574

Hirsch,I.J.,and Sherrick,C.E.Jr.
Perceived order in different sense modalities
J.Exp.Psych.,1961,62(5),423-432

Holmes,J.L.
Conductors on Record
Gollancz,1982

Holst,E.von
On the nature of order in the central nervous system,1937
In The Behavioural Physiology of Animals and Man:
The Collective Papers of Erich von Holst
University of Miami Press,1973

Honzik,C.H.
The sensory basis of maze learning in rats
Comp.Psych.Monog.,1936,13(64)

Howes,F.
Full Orchestra
London,Secker and Warburg,1942

Husserl,E.
Logical Investigations Vols I and II
J.N.Findlay (Tr.)
London,Routledge and Kegan Paul,1970

Ittelson,W.H.
The Ames demonstrations in perception
N.Y.,1968

James,W.
Principles of Psychology,1890
In F.H.Burkhardt,F.Bowes,and Skrupsketis,I.K.(Eds.)
The Works of William James,1981

Jeans,Sir J.
The Mysterious Universe
N.Y.,McMillan,1930

Jonckheere,A.R.
A Distribution-Free K-Sample test against ordered alternatives.
Biometrika,1954,41,133-145

Jones,M.R.
Cognitive representations of

serial patterns
In B.Kantowitz (Ed.)
Human information processing:
Tutorials in performance cognition
Potomac,Md.:Erlbaum,1974

Jones,M.R.
Levels of structure in the reconstruction
of temporal and spatial serial patterns
J.Exp.Psych.:Human Learning
and Memory, 1976,2,475-488

Jones,M.R.
Time,our lost dimension:Toward
a new theory of perception,attention
and memory
Psych.Rev.,1976,83(5),323-355

Jones,M.R.
Only time can tell:On the
topology of mental space and time
Critical Inquiry,1981,7(3),557-576

Jung,C.G.
On Psychic Energy
1928,In H.Read,M.Fordham,and G.Adler(Eds.)
The Collected Works of Carl G.Jung
Vol.8,Princeton,Princeton Univ. Press,1960

Jung,C.G.
Aion
1951,In The Collected Works,etc,Vol.9(ii)

Jung,C.G.
Correspondence with E.A.Bennet
In C.Bunting. Some unpopular ideas
about tension. Lecture at the
2nd Ann.Conf.Internat.Soc.for the
Study of Tension in Performance,1983

Keele,S.W.,and Posner,M.I.
Processing in visual feedback in
rapid movements
J.Exp.Psych.,1968,77(1),155-158

Kelso,J.A.S.(Ed.)
Human Motor Behaviour:an Introduction
Lawrence Erlbaum Assocs.,New Jersey,1982

Kelso,J.A.S.,Southard,D.L.,and Goodman,D. (a)
On the coordination of two-handed movements
J.Exp.Psych.:Human Perception and
Performance,1979,5,229-238

Kelso.J.A.S.,Southard,D.L.,and Goodman,D. (b)
On the nature of human interlimb coordination
Science,1979,203,1029-1031

Kelso,J.A.S.,and Holt,K.G.
Exploring a vibratory systems account of
human movement production
J.Neurophysiol.,1980,43,1183-1196

Kelso,J.A.S.,Holt,K.G.,Rubin,P.,and Kugler,P.N.
Patterns of human interlimb coordination

emerge from the properties of non-linear
limit cycle oscillatory processes:
Theory and data
J.Motor.Beh.,1981,13(4),226-261

Keselman,H.J. and Leventhal,I.
Concerning the statistical procedures
enumerated by Gentile et al:
Another perspective.
J.App.Beh.Anal.,1974,7,643-645

Klapp,S.T.
Doing two things at once:the role
of temporal compatibility
Memory and Cognition,1979,7,375-81

Kornhuber,H.H.
Cerebral cortex,cerebellum,and basal ganglia:
An introduction to their motor functions
In F.O.Schmitt and F.G.Worden(Eds.)
The Neurosciences.Third Study Programme
Cambridge,MIT Press,1974

Kozhevnikov,V.A.,and Chistovich,L.A.
Speech:Articulation and perception
(Joint Public Research Service No.30543)
Washington,D.C.,U.S.Dept.of Commerce,1965

Kratochwill,T.,Alden,K.,Demuth,D.,Dawson,D.,Panicucci,C.,
Arntson,P.,McMurray,N.,Hempstead,J.,and Levin,J.
A further consideration in the application
of an analysis-of-variance model for the
intrasubject replication design.
J.App.Beh.Anal.,1974,7,629-633

Kruskal,W.H. and Wallis,W.A.
J.Amer.Statist.Ass.,1952,47,583

Kugler,P.N.,Kelso,J.A.S.,and Turvey,M.T.
On the concept of coordinative structure
as dissipative structure.I.
Theoretical lines of convergence
In G.E.Stelmach and J.Requin (Eds.)
Tutorials in Motor Behaviour
Amsterdam.North-Holland,1980

Kugler,P.N.,Kelso,J.A.S.,and Turvey,M.T.
On the control and coordination of
naturally developing systems
In J.A.S.Kelso and J.E.Clark (Eds.)
The development of movement control
and coordination
N.Y.,John Wiley,1982

Lansing,R.W.
Relation of brain and tremor
rhythms to visual reaction time
EEG.Clin.Neurophysio.,1957,9,497-504

Lashley,K.S.
The problem of serial order in Behaviour
In L.A.Jeffress(Ed.) Cerebral Mechanisms
in Behaviour

N.Y.,John Wiley and Sons,1951,112-136

Lashley,K.S.
Persistent problems in the evolution of mind
Quart.Rev.Biol.,1949,24,28-42

Lashley,K.S.
In search of the engram
Sympos.Soc.Exp.Biol.,1950,4,454-82

Lee,D.N.
A theory of visual control of braking based on information about time-to-collision
Perception,1976,5,437-459

Lee,D.N.
On the functions of vision
In H.Pick and E.Saltzman(Eds.)
Modes of Perceiving
Hillsdale,N.J.,Lawrence Erlbaum Assocs,,1978

Lee,D.N.
Visuo-motor coordination in space-time
In G.E.Stelmach and J.Requin (Eds.)
Tutorials in motor behaviour
Amsterdam,North-Holland,1980

Lee,D.N.,Lishman,J.R.
Visual proprioceptive control of stance
J.Hum.Mov.Studs.,1974,1,87-95

Lee,D.N.,Lishman,J.R.,and Thompson,J.
Visual guidance in the long jump
Athletics Coach,1977,11,26-30,and 12,17-23

Lee,D.N.,and Reddish,P.
Plummeting gannets:a paradigm of ecological optics
Nature,1981,293(5830),293-294

Lee,D.N.,Young,D.S.,Reddish,P.E.,Lough,S.,and Clayton,T.M.H.
Visual timing in hitting an accelerating ball
Quart.J.Exp.Psych.,1983,35(a),333-346

Lee,D.N.,and Young,D.S.
Visual timing of interceptive action
In D.Ingle,M.Jeannerod,and D.Lee (Eds.)
Brain Mechanisms in Spatial Vision
NATO ASI Series,Martinus Nijhoff,1985

Lehiste,I
Rhythmic units and syntactic units in production and perception
J.Acoust.Soc.Amer.,1973,54,1228-1234

Lehiste,I.
Isochrony reconsidered
J.Phonetics,1977,5,253-263

Lerdahl,F.,and Jackendorf,R.
Towards a formal theory of tonal music
J.Music Theory,1977,21,111-171

Leshowitz,B.
The measurement of the two-click

threshold
J.Acoust.Soc.Amer.,1971,49,462-466

Lincoln,Y.S.
Rational treatment of
trustworthiness
Educ.Counsel.Therap.J.,summer 1981

Longuet-Higgins,H.C.,and Lee,C.S.
The perception of musical rhythms
Perception,1982,11,114-128

Lovelock,J.E.
Gaia:a new look at life on Earth
O.U.P.,1979

Lundervold,A.J.S.
Electromyographic Investigations of Position
and Manner of Working in Typewriting
Acta Physiol.Scand.,1951,24(84)

Mann,H.B. and Whitney,D.R.
Ann.Math.Statist.,1947,18,50

Marcus,S.M.
Acoustic determinants of perceptual centre
(P-centre) location
Percept.and Psycho.,1981,30(3),247-256

Martin,J.G.
Rhythmic(hierarchical) versus serial
structure in speech and other behaviour
Psychological Review,1972,79,487-509

Martin,V.
Wilderness
The Findhorn Press,1982

Marx,K.
Essential Writings
R.L.Bender(Ed.)
N.Y.,Harper,1972

Marx,K.
Economics and Philosophic Manuscripts
In R.C.Tucker(Ed.) The Marx-Engels Reader
N.Y.Norton,1972

Maslow,A.
Towards a Psychology of Being
Princeton,Van Nos.,Reinholdt,1962

McElheren,B.
Conducting Technique for beginners
and professionals
N.Y.,1966

McGill,W.J.
Random fluctuations of response rate
Psychometrica,1962,27,3-17

McGurk,H.,and McDonald,J.
Hearing lips and seeing voices
Nature,1976,264,746-748

Michael,J. (a)
Statistical Inference for Individual
Organism Research:Some reactions to a

suggestion by Gentile,Roden,and Klein.
J.App.Beh.Anal.,1974,7,627-628

Michael,J. (b)
Statistical Inference for Individual Organism Research:Mixed blessing or curse?
J.App.Beh.Anal.,1974,7,647-653

Michon,J.
Timing in temporal tracking
Soeterberg,The Netherlands:
Instit.voor Zintuigfysiolog.,RVO-TNO,1967

Michon,J.
Programs and "programs" for sequential patterns in motor behaviour
Brain Research,1974,71,413-424

Milner-Brown,H.S.,Stein,R.B.,Yemm,R.
Changes in firing rate of human motor units during linearly changing voluntary contractions
J.Physiol.,1973,220,371-390

Monod,J.
Chance and Necessity
N.Y.,Knopf,1971

Moore,G.
The Unashamed Accompanist
Methuen,1943

Morton,J.,Marcus,S.M.,and Frankish,C.R.
Perceptual Centres(P-Centres)
Psych.Rev.,1976,83,405-408

Mozart,W.A.
Correspondence
In E.Holmes(Ed.) The Life of Mozart Including his Correspondence
Chapman and Hall,1878,211-13

Newell,K.M.
The speed-accuracy paradox in movement control:errors of time and space
In G.E.Stelmach and J.Requin(Eds.)
Tutorials in Motor Behaviour
Amsterdam,North-Holland,1980

Newell,K.M.,Hoshizaki,L.E.F.,Carlton,M.J.,and Halbert,J.A.
Movement time and velocity as determinants of movement timing accuracy
J.Motor Beh.,1979,11,49-58

Newell,K.M.,Carleton,L.G.,Carleton,M.J.,and Halbert,J.A.
Velocity as a factor in movement timing accuracy
J.Motor Beh.,1980,12,47-56

Noteboom,S.G.
Some effects on phonemic categorization of vowel duration
I.P.O.Annual Progress Report,1974,9,47-55

Oatley,K.
Perceptions and Representations:

The theoretical basis of brain research and psychology
Methuen,1978

Pavlov,I.P.

Conditioned Reflexes.An Investigation of the Physiological Activity of the Cerebral Cortex,1927
G.V.Andrep (Tr.)
N.Y.,New Dover Edition,1960

Peters,M.

Simultaneous performance of two motor activities:the factor of timing
Neuropsych.,1977,15,461-4

Peters,M.

Attentional asymmetries during concurrent bimanual performance
Quart.J.Exp.Psych.,1981,33(a),95-103

Peters,M.,and Durding,B.M.,

Handedness measured by finger tapping: a continuous variable
Canadian J.Psych.,1978,32,257-61

Pick,A.

Die Agrammatischen Sprachstorungen
Berlin,1913

Polanyi,M.

Personal Knowledge:Towards a post-critical philosophy
London,1958

Polanyi,M.

Knowing and Being;Essays
M.Grene(Ed.),London,1969

Polanyi,M.,and Prosch,H.

Meaning
London,University of Chicago Press,1975

Popper,Sir K.R.

Conjectures and Refutations;the growth of scientific knowledge
London,1963

Poulton,E.C.

Tracking skill and manual control
Academic Press,1974

Povel,D.J.L.

Temporal structure of performed music. Some preliminary observations
Acta Psych.,1977,41,309-320

Povel,D.J.L.

Internal representations of simple temporal patterns
J.Exp.Psych.:Human Perception and Performance,1981,7(1),3-18

Previn,A.

Orchestra
London,MacDonald and Janes,1979

Priestley,J.
Hartley's theory of the human mind,on the principle of the association of ideas. With essays relating to the subject of it, by J.Priestley
2nd Edition,London,1790.

Raibert,M.H.
Motor control and learning by the space-state model
Tech.Report,A.I.Laboratory,MIT,1977

Ramsay,D.S.,Campos,J.J.,and Frenson,L.
Onset of bimanual handedness in infants
Inf.Beh.and Devel.,1979,2,69-76

Rapp-Holmgren,K.
A study of syllable timing
Quarterly Status and Progress Report 1-1971
Stockholm,Sweden Speech Transmission Laboratory, 1971

Rasch,R.A.
Synchronisation in performed ensemble music
Acustica,1979,43,121-131

Reece,P.
A model of temporal tracking
Acta Psych.,1976,40,385-404

Reger,S.N.
The string instrument vibrato
In S.N.Reger and C.E Seashore (Eds.)
The vibrato:University of Iowa studies in the psychology of music,Vol I,Pp 305-319

Revesz,G.
Introduction to the Psychology of Music
University of Oklahoma Press,1954

Rogers,C.
Client-Centered Therapy
Boston,Houghton Mifflin,1951

Rogers,C.
On Encounter Groups
N.Y.,Harper and Row,1970

Rosenbaum,D.A.
Human Movement Initiation:Specification of arm direction and extent
J.Expt.Psychol:General,1980,109,444-474

Schiff,W.,and Detwiler,M.L.
Information used in judging impending collision
Perception,1979,8,647-58

Schilpp,P.(Ed.)
Albert Einstein, Philosopher-Scientist
Vol I,N.Y.,Harper and Row,1949

Schlapp,M.

Observations on voluntary tremor-
violinist's vibrato
Quart.J.Exptl.Physiol.,1973,58,357-368

Schmidt,R.A.,Zelaznik,H.M.,Hawkins,B.,Frank,J.S.,and Quinn,J.T.
Motor-output variability:a theory for the
accuracy of rapid motor acts
Psych.Rev.,1979,86,415-451

Schonen,S.de
Functional asymmetries in the development
of bimanual coordinations in human infants
J.Hum.Mov.Studs.,1977,3,144-56

Schumacher,F.
A Guide for the Perplexed
Abacus,1977

Seashore,C.E.
The Psychology of Musical Talent
Boston,Silver Burdett,1919

Seashore,C.E.
Psychology of Music
Mcgraw-Hill,1938

Shaffer,L.H.
Latency mechanisms in transcription
In S.Kornblum(Ed.) Attention and Performance
N.Y.,Academic Press,1973

Shaffer,L.H.
Analysing piano performance:
A study of concert pianists
In G.E.Stelmach and J.Requin (Eds.)
Tutorials in motor behaviour
Amsterdam,North-Holland,1980

Shaffer,L.H.
Performances of Chopin,Bach,and Bartok:
Studies in motor programming
Cog.Psych.,1981,13,326-376

Shaffer,L.H.
Rhythm and timing in skill
Psych.Rev.,1982,89(2),109-122

Shaffer,L.H.
Timing in solo and duet piano performances
Quart.J.Exp.Psych.,1984,36(a),577-595

Shik,M.L.,and Orlovski,G.N.
Coordination of the limbs
during running of the dog
Biophysics,1965,10,1148-1159

Shik,M.L.,Orlovski,G.N.,and Severin,
Organisation of locomotor synergies
Biophysics,1966,10,1011-1019

Siegal,S.
Nonparametric statistics for the
behavioural sciences
N.Y.,McGraw-Hill,1956

Sillito,G.P.
Biometrika,1947,34,36

Sinnot,E.W.
The creativeness of life
In H.H.Anderson(Ed.) Creativity and its Cultivation
Harper,1959,21-9

Skinner,B.F.
Beyond Freedom and Dignity
Penguin,1971

Skinner,B.F.
Cumulative Record:a Selection of Papers
III Edit.,N.Y.,Meredith,1972

Skolimowski,H.
Eco-Philosophy
N.Y.,M.Boyars,1981

Sloboda,J.A.
Music performance
In D.Deutsch (Ed.)
The Psychology of Music
N.Y.,Academic Press,1982

Sloboda,J.A.
The communication of musical metre in piano performance
Quart.J.Exptl.Psych.,1983,35(a),377-396

Smith,F.J.
The Experiencing of Musical Sound:
A Prelude to a Phenomenology of Music
N.Y.,Gordon and Breach,1979

Smith,J.K.
Quantitative research versus qualitative research
Educ.Research.,1983,12(3)

Spence,K.
Living Music
London,Hamish Hamilton,1979

Spender,S.
The Making of a Poem
In B.Ghiselin(Ed.) The Creative Process: a Symposium
Univ.Calif.Press,1952 edition,112-25

Spinoza,B.
Ethics et de Intellectus Emendatione
A.Boyle(Tr.),first publ.1677
London,Everyman,1959

Spinoza,B.
The political works;the Tractatus
A.G.Wenham(Tr.)
Oxford,1958

Stager,P.,and Laabs,G.J.
The effect of divided attention on probe reaction time in multiple task performance
Canad.J.Psych.,1977,31,174-83

Stapp,H.P.
Whiteheadian Approach to Quantum Theory

and the Generalised Bell's Theorem
Foundations of Physics,1979

Stelmach,G.E.
Information-Processing Framework
for Understanding Human Motor Behaviour
In J.A.S.Kelso(Ed.) Human Motor Behaviour,
an Introduction,1982,63-137

Stetson,R.H.
A motor theory of rhythm
and discrete succession
Psych.Rev.,1905,12,250-270

Stetson,R.H.,and Tuthill,T.E.
Measurement of rhythmic unit groups
at different tempos.
Psych.Monog.,1923,32,41-51

Steedman,M.J.
The Blues and the Abstract Truth:
A generative grammar for jazz
chord sequences
(Reference note 1.1)

Sudnow,D.
Ways of the Hand:
The Organisation of Improvised Conduct
Routledge and Kegan Paul,1978

Sullivan,H.S.
The Interpersonal Theory of Psychiatry
H.S.Derry and M.L.Garrel (Eds.)
N.Y.,1953

Summers,J.J.
The role of timing in motor program
representation
J.Mot.Beh.,1975,7,229-241

Taubman,R.E.
Studies in judged number.I.
The judgement of auditory number
J.Gen.Psych.,1950,43,167-194

Tchaikovsky,P.I.
Correspondence
In R.Newmarch(Ed.) Life and Letters of
Peter Ilich Tchaikovsky
John Lane,1906,274-5

Ten Hoopen,M.,and Reuver,H.A.
Analysis of sequences of events with
random displacements applied to
biological systems
Math.Biosc.,1967,1,599-617

Thoresen,C.E. and Elashoff,J.D.
"An analysis-of-variance model for
intrasubject replication design":
some additional comments.
J.App.Beh.Anal.,1974,7,639-641

Titchener,E.B.
Lectures on the Experimental Psychology

of the Thought Process
N.Y.,McMillan,1909

Titchener,E.B.
A Text-book of Psychology
N.Y.,1915

Toynbee,A.
A Study of History
O.U.P.,1972

Travis,L.E.
The relation of voluntary movements to tremors
J.Exp.Psych.,1929,12,515-524

Trevarthen,C.
The foundations of intersubjectivity: Development of interpersonal and cooperative understanding in infants
In D.Olsen (Ed.) The social foundations of language and thought: essay in honour of J.S.Bruner
N.Y.,Norton,1980

Trevarthen,C.
Biodynamic structures,cognitive correlates of motive sets, and the development of motives in infants
In W.Prinz and A.F.Sanders(Eds.) Cognition and Motor Processes
Springer-Verlag,Berlin Heidelburg,1984

Turvey,M.T.
Clues from the organisation of motor systems
In V.Bellugi and M.Studdert-Kennedy(Eds.)
Signed and spoken language: Biological constraints on linguistic form
Basel,Verlag Chemie,1980

Turvey,M.T.,Shaw,R.E.,and Mace,W.
Issues in the theory of action:degrees of freedom,coordinate structures and coalitions
In J.Requin(Ed.) Attention and Performance (VII),Hillsdale,N.J.,Lawrence Elrbaum,1978

Tyrrell,G.
Grades of Significance
London,1930

Van der Gon,J.J.D.,and Thuring,J.Ph.
The Guiding of Human Writing Movements
Kybernetik,1965,2(4),145-148

Vince,M.A.
Corrective movements in a pursuit task
Quart.J.Exp.Psych.,1948,1,85-103

Viviani,P.
Relationship between form and motion in Handwriting

(Reference note 1.2)
Viviani,P.,and Terzuolo,C.A.
Motor engrams in typing and handwriting
In G.E.Stelmach(Ed.) Tutorials in Motor
Behaviour,1980
Amsterdam:North Holland

Voillaume,C
Modeles pour l'etude de la regulation
des mouvements cadences
Annee Psych.,1971,71,347-358

Vorberg,D.,and Hambuch,R.
On the temporal control of
rhythmic performance
In J.Requin(Ed.) Attention and Performance
Hillsdale,N.J.,Lawrence Erlbaum,1978

Waddington,C.
Biology and the History of the Future
An IUBS-UNESCO Symposium,Edinburgh,1972

Waddington,C.
Tools for Thought
Paladin,1977

Warren,R.M.,and Warren,R.P.
Helmholtz in Perception;its
Physiology and Development
N.Y.,1968

Washburn,M.F.
Movement and Mental Imagery
Boston,Houghton Mifflin,1916

Watson,J.B.
Is thinking merely the action of the
language mechanisms?
Brit.J.Psych.,1920,11,86-104

Watson,J.B.
Behaviour
N.Y.,Holt,1914

Weiss,P.
Within the Gates of Science and Beyond
N.Y.,Hafner,1971

West,L.J.
Vision and kinesthesis in the
aquisition of typing skill
J.App.Psych.,1967,51(2),161-166

Whitehead,A.
Science and the Modern World
McMillan,1926

Whitehead,A.
Process and Reality
McMillan,1929

Whitehead,A.
Adventures of Ideas
McMillan,1933

Whitney,D.R.

Ann.Math.Statist.,1951,22,274

Wilcoxon,F.
Biomet.Bull.,1945,1,80

Wing,A.M.,and Kristofferson,A.B. (a)
The timing of interresponse intervals
Percept.Psychophys.,1973,13,455-460

Wing,A.M.,and Kristofferson,A.B. (b)
Response delays and the timing of
discrete motor responses
Percept.Psychophys.,1973,14,5-12

Wing,A.M.
Effect of type of movement on the
temporal precision of response sequences
Brit.J.Math.Statist.Psych.,1977,30,60-72

Wickens,C.D.
The effect of divided attention on
information processing in manual tracking
J.Exp.Psych.,1976,12,1-12

Williams,L.
The Dancing Chimpanzee
Allison and Busby,1967

Wolff,P.H.,Hurwitz,J.,and Moss,H.
Serial organisation of motor
skills in left- and right- handed adults
Neuropsych.,1977,15,539-46

Woodrow,H.
Time perception
In S.S.Stevens (Ed.)
Handbook of Experimental Psychology
N.Y.,Wiley,1951,Pp1224-1236

Woodworth,R.S.
The accuracy of voluntary movement
Psych.Rev.Monog.Suppl.,1899,3(2),54-59

Woodworth,R.S.,and Schlosberg,H.
Experimental Psychology
N.Y.,Henry Holt,Reinhart and Winston,1954

Yamanishi,J.,Mitsuo,K.,and Ryoji,S.
Studies on human finger networks
by phase transition curves
Biol.Cyber.,1979,33,199-208

Zukav,G.
The Dancing Wu Li Masters
Fontana:Collins,1979

Appendix Two

Photographs of subjects and equipment

The following photographs show the positions of the subjects and of the recording equipment.


2.1
Model

2.2

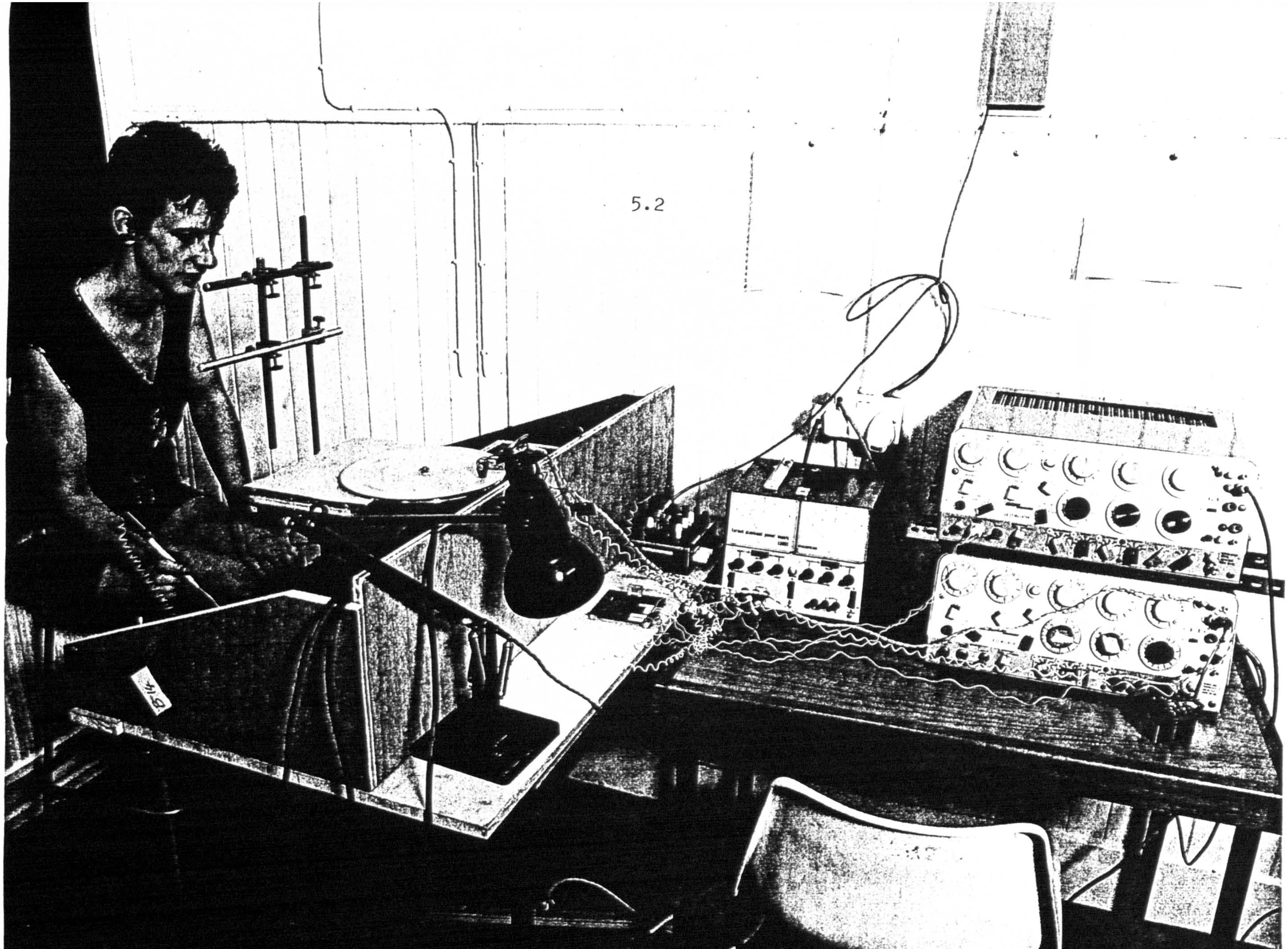

4.1


4.2


4.3


5.1

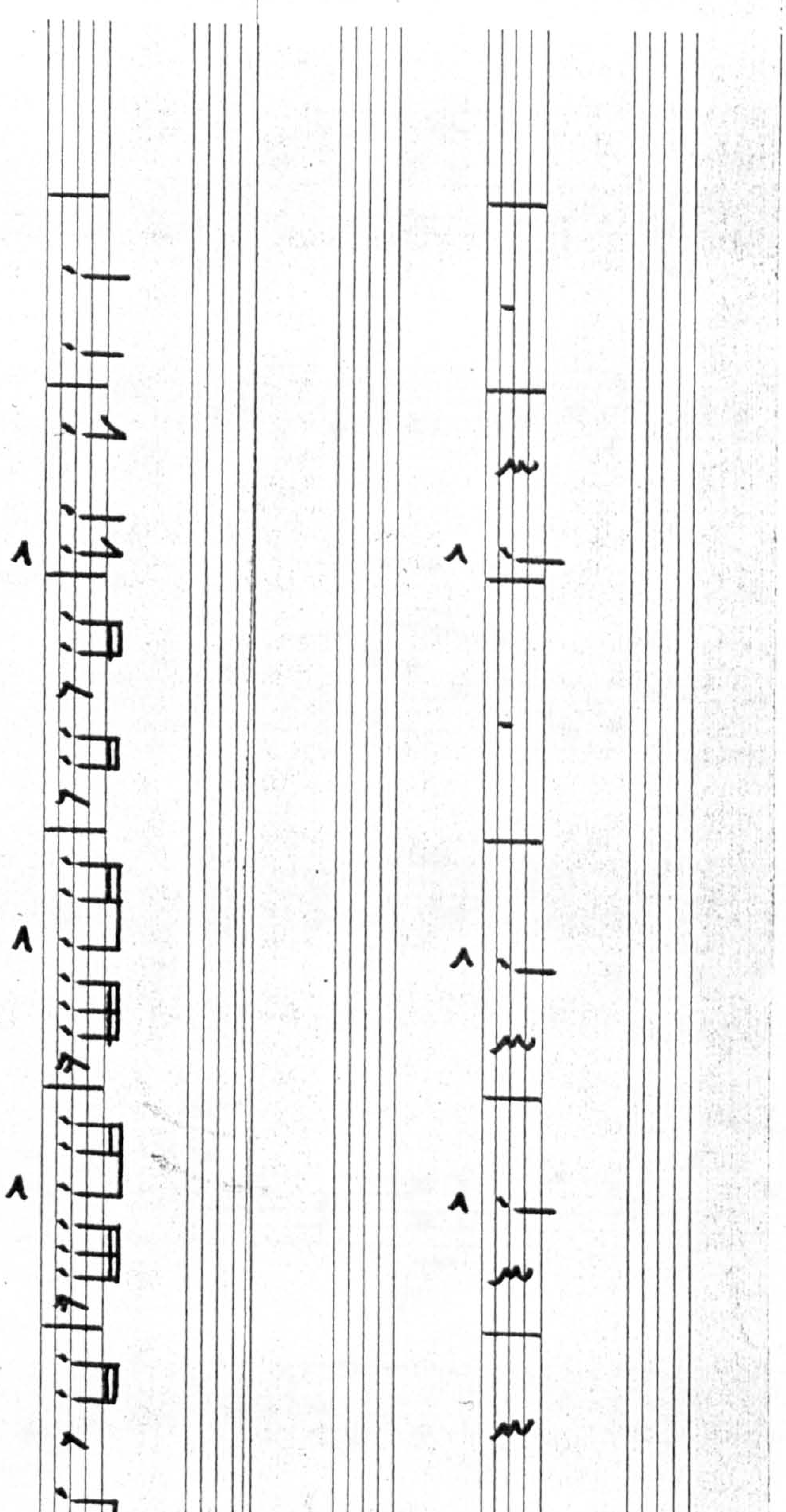
5.2



Appendix Three

Musical scores

The following are copies of the scores used in the experiments.



D: ♩= 80
E: ♩= 100
F:

44 DUOS

II. HEFT / II. FÜZET

15.

SOLDATENLIED / SOLDIERS' SONG / KATONANÓTA

Béla Bartók

(54")

Universal Edition Nr. 10452 a

27.

HINKE-TANZ / LIMPING DANCE / SÁNTA-TÁNC

(30")

Appendix Four

Details of Subjects

The experiments reported in chapters two to four involved two principal subjects, although many other musicians were involved at different stages. All were from the Music Department of Edinburgh University. Brief biographies of the two main subjects are given here to give an indication of the experience and skill that they possessed.

The conductor, Guy Thomas, had been conducting since age fifteen. He started while at school. At the time that these recordings were made, he was the conductor of his local youth orchestra in North London, and used to conduct on occasion the Edinburgh Student Orchestra at the Reid Concert Hall.

The other main participant was also a conductor. David Riddell also started conducting at school. He had no formal instruction at first, instead attempting to model his technique on the perceived good points of others. Later he went to study with Hurst of the Bournemouth orchestra and for brief periods with the resident conductors at Saddlers Wells and with the BBC symphony orchestra respectively. At the time of the recordings, he was conducting the St.Andrews amateur orchestra, and had just founded the Scottish Student Orchestra. A few weeks ago before these experiment were run, he placed second out of a field of eighty finalists who were competing for a place on a postgraduate course in conducting at the

Royal Northern College of Music, and was first reservist at the Guildhall school of Music, London.

The experiments reported in chapters six to eight also involved two musicians. The greater part of the recordings were made with one subject, whose details follow.

Principal Subject

The principal subject in the experiments reported in chapters six to eight, Alan Marshall, started his musical career when he was about six years old. There was a strong musical tradition in his family, his mother at one time was a violinist with the Welsh National Orchestra, his uncle was a professor of music.

He learned to play the violin, then the recorder and guitar. When he left school he became a professional musician, and learned to play the saxaphone. At the time of the recordings, he had other employment, but was continuing to work part-time as a musician.

He describes himself as a commercial musician, playing popular rather than avant-garde or experimental music. He has played at all levels in the music business, in Britain and abroad, with local bands as well as celebrities.

Of particular interest is that he had done session work for advertisments for both British and European television. With this kind of work, the musical piece is extremely scaled down and the timing must be extraordinarily tightly controlled. Alan said that typically one would have to play for exactly five seconds, to order. He described the work as very disciplined, as very specific types of effects would be required in addition to precise timing.

Second Subject

The replicating subject in this series, Thursa Sanderson, had been playing the piano for twenty years, from the time she was six years old, at the time that the recordings were made. She had played cello since age eleven, for fifteen years. At age seventeen she passed the Association Board Grade VII exams for both instruments. She started teaching her first two pupils in that year. She was playing on a part-time professional basis at the time, mostly folk and light rock music, although her training was formal. She was also giving a series of public performances in the 1984 Edinburgh Festival as a member of a string quartet.

Of particular interest is her experience as a cellist. In a quartet, the cellist must keep the basic beat clear, which normally entails keeping strict time. Thus with this subject, as with the others, the standard of timekeeping accuracy was assumed to be high.

Appendix Five

Programmes and major subroutines

```
C    TCTRNS
C    ....CALLS ADTRNS,A SUBROUTINE WHICH RETURNS TIMES OF POSITIVE
C    TRANSITIONS AT THE A/D CONVERTER,AND PLACES THEM IN AN ARRAY
C    CALLED TRNPOS.FOR DETAILS :TYPE ADTRNS.FOR
C    NOTES:COMPILE TIME SPECIFY NOLINE
C          LINK TIME    ADTRNS,LDPLIB,SELLIB
C    FIRST VERSION:18TH.DEC.1981                    TC
C
C
C
     DIMENSION TRNPOS(1000,3),ICNTS(3),ITSTS(3,2)
C
     LOGICAL CHOICE,MORE,PARAM,CHIZ
C
     DATA ICMAX/1000/,NCHAN/3/,IRATE/4/,RCOUNT/2./,STIME2/0./,
     & TTEND/0./,IFIRST/0/,ICSTOP/0/,RATTLE/0.100/
C
C  READ IN PARAMETER VARIABLES
C

     CALL RRDVAL ('MIN DURATION START/STOP SIGNAL',1.0,STIME)
     CALL IRDVAL ('IRATE FOR CLOCK',IRATE,IRATE)
     CALL RRDVAL ('RCOUNT FOR CLOCK',RCOUNT,RCOUNT)
C
     TYPE 104
104  FORMAT(' SET TEST LEVELS')
     DO 1,I=1,NCHAN
     TYPE 105,I
105  FORMAT(' CHANNEL',I2)
     CALL IRDVAL ('TRANSITION LUMEN',3500,ITSTS(I,1))
C  ITSTS TAKES 2 VALUES-AN UP AND A DOWN TRANSITION THRESHOLD-
C  AS LONG AS THESE ARE TO BE THE SAME,SET THE 2ND TO = THE 1ST.
     ITSTS(I,2)=ITSTS(I,1)
1    CONTINUE
C
555  CHOICE=.TRUE.
     CHIZ=.TRUE.
C
C  ASSIGN FILENAME,OPEN FILE
     TYPE 111
111  FORMAT ('$FILENAME FOR TRIAL? ')
     CALL ASSIGN(19,,-1)
C
C  READY TO CALL SUBROUTINE
C
10   TYPE 107
```

```
107 FORMAT('$TYPE <CR> WHEN READY TO RUN')
    PAUSE
    CALL ADTRNS  (TRNPOS,ICMAX,NCHAN,IFIRST,ICNTS,
    & IRATE,RCOUNT,ICSTOP,STIME,STIME2,ITSTS,IERR,TTEND)
C
C**************************************************************************
C
C  ARRAY LISTING OPTION
    CALL LRDVAL('LIST TRNPOS ARRAY',CHOICE,CHOICE)
    IF (CHOICE) GOTO 535
    GOTO 2
535 DO 30 ICHAN=1,NCHAN
30  TYPE 109, ICHAN,ICNTS(ICHAN),(TRNPOS(I,ICHAN),I=1,ICNTS(ICHAN))
109 FORMAT(/' CHANNEL',I2,I7,' TRANSITIONS; TRANSITION TIMES: '/
    & (1X,10F7.2))
    TYPE 112,TTEND
112 FORMAT((2X)' TOTAL RECORDING TIME: ',(F6.2),'SECS')
C.....................................................................
C  CONTROL FOR SWITCH RATTLE
C  (BUT IF ARRAY FOR CHANNEL ONE CONTAINS NO TRANSITIONS MOVE ON)
    IF (ICNTS(1).EQ.0) GOTO 2
    CALL LRDVAL('RUN RATTLE FILTER',CHIZ,CHIZ)
    IF (.NOT.(CHIZ)) GOTO 2
C  FIND NO OF TRANSITIONS ON CHANNEL ONE
    NOTRA=ICNTS(1)
C  INITIALIZE I
    I=3
C  IS GAP BETWEEN PULSES BIG ENOUGH?
231 IF ((TRNPOS(I,1)-TRNPOS(I-2,1)).GT.RATTLE) GOTO 228
C  NO? THEN REMOVE THAT PULSE BY SHUFFLING THE OTHER ELEMENTS DOWN
    NOTRA=NOTRA-2
    DO 230 J=I,NOTRA
230 TRNPOS(J,1)=TRNPOS(J+2,1)
    GO TO 231
C  END OF LOOP
228 I=I+2
    IF (I.LE.NOTRA) GOTO 231
C  WHEN FINISHED FILTERING,LIST NEW ARRAY (CHANNEL 1 ONLY)
    TYPE 898
898 FORMAT (13X,'..FILTERED ARRAY..')
C  BUT FIRST RESET ICNTS(CHANNEL 1) TO NEW VALUE
    ICNTS(1)=NOTRA
    TYPE 901,1,ICNTS(1),(TRNPOS(I,1),I=1,ICNTS(1))
901 FORMAT(/' CHANNEL',I2,I7,' TRANSITIONS; TRANSITION TIMES: '/
    & (1X,10F7.2))
C.....................................................................
C
C
C  WRITE OPTION
2   CALL LRDVAL('WRITE TO DISK',CHOICE,CHOICE)
    IF(.NOT.CHOICE) GOTO 3
C
    DO 303 J=1,NCHAN
```

```
C  FIND THE NO.OF TAPS-AS OPPOSED TO ON & OFF TRANSITIONS
    NTAP=ICNTS(J)/2
    WRITE(19) 0,0,0,1.,1.,NTAP,0,0,0,0,0
303 WRITE(19) (TRNPOS(I,J),I=1,ICNTS(J),2)
C
C  N.B. IN THE WRITE STATEMENT ON LINE 303 TRNPOS IS SET TO START
C  AT THE FIRST ELEMENT THEN INCREMENT BY 2.THUS ALL THAT IS KEPT
C  ARE THE "ONS" OF EACH TAP. "OFFS",AND THEREFORE TAP DURATIONS,
C  ARE NOT KEPT.
C
C  CLOSE FILE
    CALL CLOSE(19)
C
C...............................................................
C
C  MORE RECORDING OPTION
3   CALL LRDVAL ('MORE RECORDING',.TRUE.,MORE)
    IF(MORE) GOTO 555
C  PARAMETER LISTING OPTION
    CALL LRDVAL(' PARAMETER LISTING',.TRUE.,PARAM)
    IF(PARAM) GOTO 545
    STOP 'NO PARAMETER LISTING'
545 TYPE 115,IFIRST,ICSTOP,STIME
115 FORMAT(' STARTING CHANNEL: ',I2,/
    & (1X)' START+STOP SIGNALS CHANNEL: ',I2,/
    & '  MIN.DURATION START+STOP SIGNALS: ',F7.5,'(SEC.)')
    TYPE 116
116 FORMAT((2X)' TEST LEVELS')
    DO 20,I=1,NCHAN
    TYPE 117,I,ITSTS(I,1)
117 FORMAT((1X)' CHANNEL',I2,' TRANSITION LUMEN: ',I6)
20  CONTINUE
    STOP ' END SESSION '
    END
C ADTRNS
C
C RETURNS LIST OF TRANSITIONS ON SPECIFIED CHANNELS OF THE A/D
C CONVERTORS
C
C RECORDING STARTS WHEN THE SPECIFIED CHANNEL GOES LOW FOR A GIVEN
C PERIOD (STIME2) AFTER HAVING BEEN HIGH FOR A PERIOD (STIME).
C ONCE THE CHANNEL HAS BEEN HIGH FOR STIME, RECORDING ALWAYS
C STARTS IMMEDIATELY AFTER IT HAS BEEN LOW FOR STIME2, EVEN IF
C BEFORE THE HIGH-TO-LOW TRANSITION IT HAD NOT BEEN HIGH
C FOR AS LONG AS STIME.
C RECORDING STOPS AFTER THE SAME CHANNEL HAS BEEN
C CONTINUOUSLY HIGH FOR STIME.  THE LAST TIME RETURNED HOWEVER IS
C THE TIME OF THE LAST TRANSITION ON ANY CHANNEL BEFORE THE LAST
C LOW TO HIGH TRANSITION ON THE TEST CHANNEL.
C
C PARAMETERS
C TRNPOS- ARRAY RETURNING A LIST OF TIMES AT WHICH TRANSITIONS
C OCCURRED
```

```
C THE FIRST SUBSCRIPT SPECIFIES THE NUMBER OF THE TRANSITION,THE
C SECOND THE CHANNEL ON WHICH THE TRANSITON OCCURRED.
C ICMAX- THE FIRST DIMENSION OF TRNPOS
C NCHANS- THE SECOND DIMENSION OF TRNPOS AND NUMBER OF CHANNELS TO
C SAMPLE
C IFIRST- THE NUMBER OF THE STARTING CHANNEL
C ICNTS- ARRAY RETURNING THE NUMBER OF TRANSITIONS ON EACH CHANNEL
C IRATE- CLOCK RATE,AS IN SETR
C RCOUNT-CLOCK COUNT,AS IN SETR
C ICSTOP- CHANNEL NUMBER ON WHICH START AND STOP SIGNALS WILL BE
C SENT
C STIME- THE MINIMUM DURATION OF A STOP OR START SIGNAL
C STIME2 - THE WAIT PERIOD AFTER A START SIGNAL (MAY BE ZERO)
C ITSTS- ARRAY GIVING THE TEST LEVELS FOR DETECTING TRANSITIONS.THE
C FIRST SUBSCRIPT SPECIFIES THE CHANNEL CONCERNED, THE SECOND
C SPECIFIES WHETHER THE VALUE IS TO BE USED FOR UPWARD
C OR DOWNWARD TRANSITIONS.
C THE FIRST DIMENSION IF ITSTS IN THE MAIN PROG MUST BE EQUAL TO
C NCHANS.
C IERR- RETURNS 0 ON SUCCESSFUL EXIT,1 IF DATA OVERRUN ,2 IF TOO
C MANY TRANSITIONS OCCCUR.
C TTEND - RETURNS THE TOTAL TIME OF THE RECORDING
C
C D.S.YOUNG     12 NOVEMBER 1981
C
      SUBROUTINE ADTRNS (TRNPOS,ICMAX,NCHANS,IFIRST,ICNTS,
      & IRATE,RCOUNT,ICSTOP,STIME,STIME2,ITSTS,IERR,TTEND)
C
      LOGICAL TSTCHN,READY,ON,UP,UPS(16)
C
      DIMENSION IBUF(2048),TRNPOS(ICMAX,NCHANS),ICNTS(NCHANS),
      & ITSTS(NCHANS,2)
C
      DATA MIBSIZ/2048/,NSUBAR/4/
C
      NPART=(MIBSIZ/NSUBAR)/NCHANS
C
C INITALISE
      IERR=0
      ICST=ICSTOP-IFIRST+1
      DO 1 I=1,NCHANS
      ICNTS(I)=0
1     UPS(I)=.FALSE.
      T=0.
      TIM=0.
      UP=.FALSE.
      ON=.FALSE.
      READY=.FALSE.
      TEND=0.
      TIMING=RCOUNT*10.**(IRATE-7)
      IBSIZ=NPART*NSUBAR*NCHANS
      ILEN=NPART*NCHANS
      IS=-ILEN
```

```
      ICEND=0
      IEND=0
C
D     TYPE *, ITSTS
C
C SET UP A/D SAMPLING
      CALL RTS (IBUF,IBSIZ,NSUBAR,-1,IFIRST,NCHANS,1,2,IEND,NLEFT)
      IF (IEND.NE.0) STOP 'RTS CALL ERROR'
C
C START CLOCK
      CALL SETR(IRATE,9,RCOUNT,ICEND)
      IF (ICEND.NE.0) STOP 'SETR CALL ERROR'
C
      TYPE 88
88    FORMAT (' WAITING')
C
C WAIT FOR A BUFFER TO FILL
100 IF (NLEFT.EQ.NSUBAR.AND.IEND.EQ.0) GO TO 100
C  CHECK FOR AN OVERRUN
      IF (IEND.NE.0) GO TO 991
C
C BUMP BUFFER
      IS=IS+ILEN
      IF (IS.EQ.IBSIZ) IS=0
      IFIN=IS+ILEN
      IST=IS
      IF (ON) GO TO 110
C
C LOOK FOR START SIGNAL
C
C SET UP LIMITS
      ITSTH=ITSTS(ICST,1)
      ITSTL=ITSTS(ICST,2)
      ISTART=IST+ICST
C
C START LOOP THROUGH BUFFER
D     TYPE 811, ISTART,IFIN,NCHANS,UP,ITSTH,ITSTL
D 811        FORMAT (' START WAITING LOOP',3I8,L8,2I8)
      DO 105 IPTR=ISTART,IFIN,NCHANS
      T=T+TIMING
C
      IF (UP) GO TO 106
C LOW - CHECK WHETHER TO JUMP TO MAIN LOOP
      IF (READY.AND.T.GT.TTEST) GO TO 107
      IF (IBUF(IPTR).LE.ITSTH) GO TO 105
C UPWARDS TRANSITION
      UP=.TRUE.
      TTEST=T+STIME
      GO TO 105
C
C HIGH
106 IF (IBUF(IPTR).GT.ITSTL) GO TO 105
C DOWNWARDS TRANSITITON
```

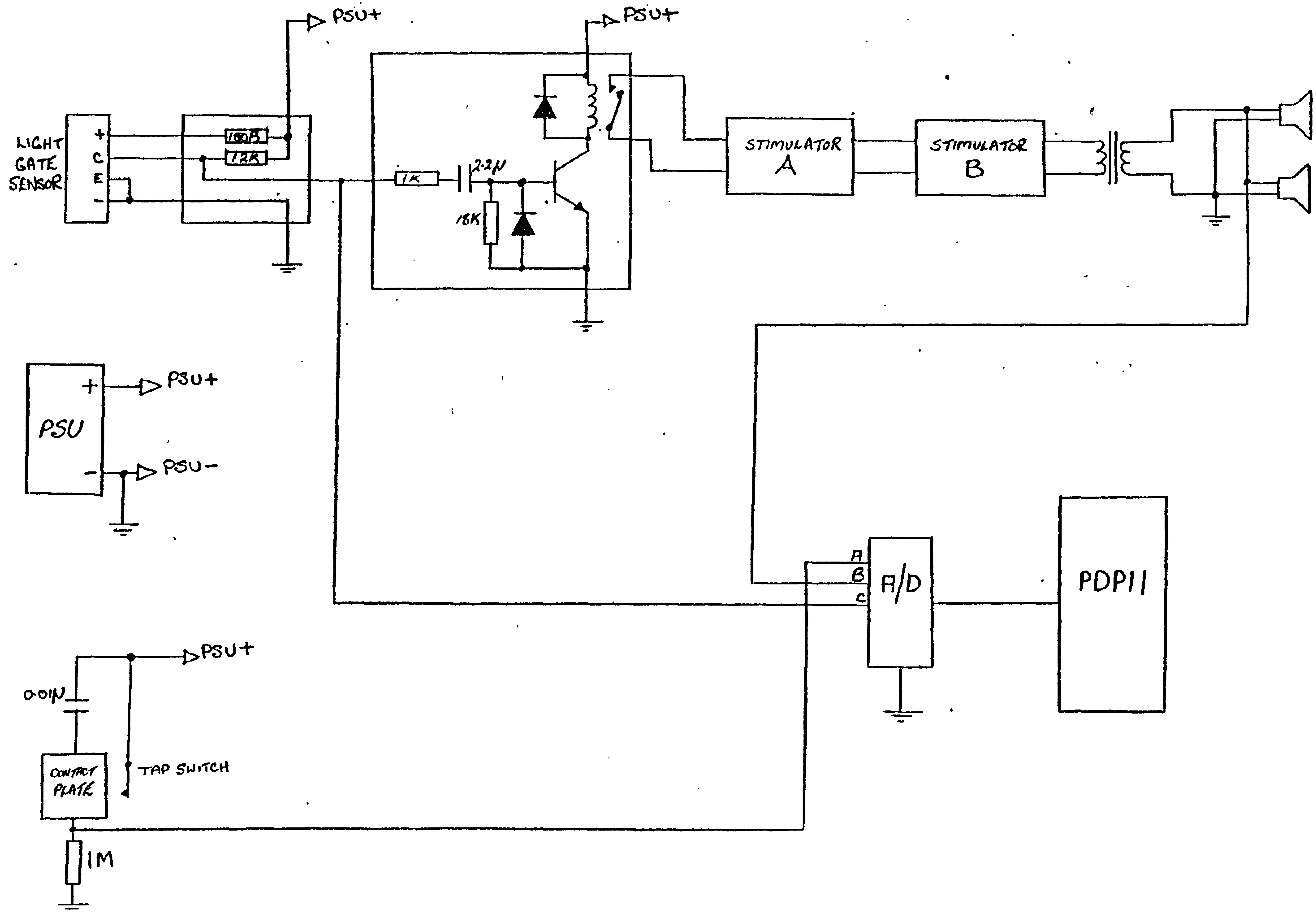
```
      UP=.FALSE.
      READY=T.GT.TTEST.OR.READY
      TTEST=T+STIME2
      GO TO 105
C
C LEAVE WAITING LOOP AND SET UP TIME TO START MAIN LOOP
107 TYPE 55
55    FORMAT (' STARTING')
      IST=IPTR-ICST+NCHANS
      ON=.TRUE.
      TIM=0.
      IF (IST.GT.IFIN) GO TO 108
      GO TO 110
C
105 CONTINUE
C
C END OF LOOP-GO TO NEXT BUFFER
108 NLEFT=NLEFT+1
      GO TO 100
C
C NOTE TRANSITIONS
C
C
C START LOOP OVER CHANNELS
110 DO 130 ICH=1,NCHANS
      T=TIM
      ITSTH=ITSTS(ICH,1)
      ITSTL=ITSTS(ICH,2)
      UP=UPS(ICH)
      ICNT=ICNTS(ICH)
      ISTART=IST+ICH
      TSTCHN=ICH.EQ.ICST
C
C START LOOP OVER SAMPLES
D     TYPE 822, ISTART,IFIN,NCHANS
D 822         FORMAT (' START MAIN LOOP',3I8)
      DO 140 IPTR=ISTART,IFIN,NCHANS
      T=T+TIMING
      IF (UP) GO TO 141
      IF (IBUF(IPTR).LE.ITSTH) GO TO 140
C UPWARDS TRANSITION
      UP=.TRUE.
      IF (TSTCHN) TTEST=T+STIME
      GO TO 139
C
C HIGH
141 IF (IBUF(IPTR).GT.ITSTL) GO TO 140
C DOWNWARDS TRANSITION
      UP=.FALSE.
C CHECK FOR STOP SIGNAL
      IF (TSTCHN.AND.T.GT.TTEST.AND.TEND.EQ.0.) TEND=T
C RECORD TIME OF TRANSITION
139           ICNT=ICNT+1
```

```
      IF (ICNT.GT.ICMAX) ICNT=ICMAX
      TRNPOS(ICNT,ICH)=T
  140 CONTINUE
C
C END OF LOOP OVER SAMPLES
C
      ICNTS(ICH)=ICNT
  130 UPS(ICH)=UP
C
C END OF LOOP OVER CHANNELS
C
      TIM=T
C
C BACK TO GET NEXT BUFFER
      NLEFT=NLEFT+1
      IF (UPS(ICST).AND.T.GT.TTEST.AND.TEND.EQ.0.) TEND=T
      IF (TEND.EQ.0.) GO TO 100
C
C END SAMPLING
C
  150 CALL RTS(,IBSIZ,,,,,,-4,IEND,NLEFT)
  151 IF (IEND.EQ.0) GO TO 151
      CALL SETR(-1,,,)
C
C TIDY UP END BY REMOVING BITS AFTER LAST LOW TO HIGH TRANSITION
C FIND TIME OF SAID TRANSITION
      IFIN=ICNTS(ICST)
      DO 210 ICNT=2,IFIN
  210 IF (TRNPOS(ICNT,ICST).EQ.TEND) TEND=TRNPOS(ICNT-1,ICST)
      IF (TEND.EQ.T) TEND=TRNPOS(IFIN,ICST)
C REMOVE TIMES AFTER AND UP TO THIS
      DO 220 ICH=1,NCHANS
      IFIN=ICNTS(ICH)
      IF (IFIN.EQ.0) GO TO 220
      ICNT=0
      DO 230 I=1,IFIN
  230 IF (TRNPOS(I,ICH).LT.TEND) ICNT=I
      IF (IFIN.EQ.ICMAX.AND.ICNT.EQ.ICMAX-1) TYPE 9902, ICH+IFIRST-1
 9902         FORMAT (' WARNING: TOO MANY COUNTS ON CHANNEL',I3)
      ICNTS(ICH)=ICNT
  220 CONTINUE
C
      TTEND=TEND
      RETURN
C
C ERROR CONDITIONS
  991 TYPE 9901
 9901         FORMAT(' ERROR: DATA OVERRUN')
      IERR=1
      GO TO 150
      END
```

Appendix Six

Circuit diagram

The following is a copy of the circuit diagram of the recording equipment used in chapters six to eight.



LIGHT GATE SENSOR
+
C
E
-
180R
12K
PSU+
1K
2.2µ
18K
PSU+
STIMULATOR A
STIMULATOR B
PSU
+
-
PSU+
PSU-
A
B
C
A/D
PDP11
0.01µ
PSU+
CONTACT PLATE
TAP SWITCH
1M